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STATISTICAL APPROACHES TO SOME PROBLEMS OF INDUSTRIAL PREVENTIVE MEDICINE*

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IT IS generally recognized that an employer is under an obligation not to submit an employee to working conditions which are injurious to his health. For many industries and occupations, the provision of safe working conditions involves no particular problems. In the chemical industries, however, or in industries using or handling chemicals, the situation is not so clear. A great many new chemicals have been coming into use, both as intermediates and as end products, and relatively little may be known about the physiological effects of many of them.

This situation has resulted in the necessity for a broad program of industrial preventive medicine, the main purpose of which is to *prevent* workers from becoming injured by their chemical environment. In the main, the practice of medicine has been directed mostly toward the diagnosis and treament of pathological conditions, and the tech-

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niques developed for these purposes may have little application to the problems of prevention of pathological changes.

In order to define the problems of industrial preventive medicine more closely, attention might be called to the fact that there is no precise way of even defining, except perhaps intuitively, what might be termed a state of good health. We recognize such a state, however, as one in which the individual is able to work and live effectively and without undue strain on his inner resources. We recognize another state of health in which we are able to work and live, but only under a feeling of tension, strain or discomfort. The stresses responsible for such a state may be primarily psychic, or primarily somatic, but whatever their origin, the final effects produced are usually somatic. Finally, there is a state of health in which excessive changes in the physical, chemical, or functional components of the organism cause a definite impairment in the ability of the individual to lead a normal existence.

A state of good health in a worker is desirable because: (1) there is then no question of chemical poisoning; and (2) healthy workers are the most productive and apparently enjoy the best personal relations with each other and with management. Unhealthy workers are undesirable because: (1) there is always a question as to how much of their ill health is due to occupational causes; (2) a worker in a state of bad health may be unduly susceptible to the effects of otherwise harmless amounts of chemicals; (3) exposure to chemicals may aggravate a pathological condition of non-occupational origin; and (4) unhealthy workers are apt to be irritable, hard to get along with, and are probably more prone to that type of human failure which leads to accidents.

How are the aims of industrial preventive medicine to be accomplished? General information about the effects of chemicals can, of course, be obtained by the process of experimentation on laboratory animals. By the use of statistical techniques which have been developed in recent years, the LD_{50} of a given compound can be determined with almost any desired degree of precision on experimental animals. From a knowledge of the LD_{50} of a given chemical for one or more species of animals, one can usually predict whether or not the chemical is apt to be very toxic or not very toxic for human beings. There is no way, however, of extrapolating and calculating the lethal dose of a compound for human beings from ever so exact knowledge of its lethal dose for

one or more species of animals. Attempts to do this in the past have led to some notable errors. Furthermore, knowledge of the lethal dose of a compound, even for man, is of very little use in a program of preventive medicine, the aim of which is to keep men well, and not merely to prevent them from dying.

It is our belief that ultimately the best possible source of information about the effects of chemicals on human beings is to be found in observations on human beings. Not only are the data so obtained directly applicable to the species in which one is most interested, but the detection of toxic effects in an individual gives the physician an opportunity to take immediate corrective measures. On the other hand, as was pointed out, the usual diagnostic procedures of medicine are geared to detect pathological changes after they have occurred, and the detection of such changes is of no comfort to the industrial physician, for they merely confirm his failure to prevent.

There is, unfortunately, no known way of assessing by any simple test the goodness of health of an individual. The human organism is too complex for that. The very complexity of the organism, however, is the factor which provides some hope for the program of prevention. The organism is so complex, that in order to function properly, its internal environment must be very exactly regulated. Claude Bernard recognized this in his statement: *"La fixité du milieu intérieur est la condition de la vie libre."* L. J. Henderson (1) expressed somewhat the same idea in 1913, when he wrote: "When these ideas are reduced to their very simplest forms, it appears that life must be highly complex in structure and function; that the conditions of the environment must be regulated, and that there must be very exact regulation of conditions, both structural and functional, within the organism, and finally, that, while life is active, there must be exchange of both matter and energy with the environment."

With the stability of the internal environment in mind, there would appear to be some hope of detecting variations in the over-all state of health of the organism through detection of variation in elements of the internal environment, structural or functional. To be useful, however, these variations must be detectable before they pass into the realm of the pathological.

It occurred to us that our concept of the problem of industrial preventive medicine was somewhat analogous to that of a manufacturer who wishes to make sure that the quality of the product he is producing

is up to standard. When the quality of the product meets specifications, it is satisfactory for its purpose. When it fails to meet specifications the product has to be scrapped, resulting in economic waste. Thus, in mass production it is important to be able to detect variation in quality of the units being turned out, before the deterioration in quality becomes serious enough to require scrapping of material. From the point of view of industrial preventive medicine, it is important to detect variation in health of the worker before the variation becomes great enough to be considered pathological, resulting in lost time and productivity.

Certain statistical techniques which have been developed in recent years have been of great help in the field of industrial quality control. It seemed worth while to at least try to apply some of these techniques to the field of industrial preventive medicine, and this paper is concerned with an exposition of some attempts along these lines.

In order to avoid trouble from the toxic effects of chemicals, it would appear important to do at least three things: (1) specify that the health of the workers shall come up to certain standards before they are employed on an operation involving exposure to chemicals; (2) specify to the best of one's ability the conditions under which the operation should be safe—even the most dangerous of chemicals can be handled safely if adequate precautions are taken; and (3) inspect the workers periodically to determine whether or not deterioration of health has taken place, and if so, from what causes. While it is often difficult to obtain workers whose health comes up to rigid standards, the problem of inspection is the one which offers the most theoretical difficulties.

Chance observation and certain theoretical considerations led us to believe that we might derive some profit from study of the blood pressure in workers. On the experimental side, it was observed that workers who developed frank symptoms of chemical poisoning usually showed abnormal blood pressures in advance of their specific symptoms. On the theoretical side, it could be argued that the blood pressure reflects the condition of the circulation of the blood, which is a highly integrated function in the human organism, and which might, therefore, be one of the first to reflect the presence of a disturbing factor in the organism. Furthermore, the measurement of blood pressure can be made quickly and simply by a standard technique which does not alarm or inconvenience the worker or require extended absence from his work.

While there is no general agreement among members of the medical profession as to what constitutes a normal blood pressure, most physicians would agree that there is such a thing for any given individual. We attempted to test this hypothesis in two ways: (1) by studying the variation in blood pressure of normal dogs maintained in the laboratory for a period of months, and (2) by analyzing the medical records of employees in whom there was never any evidence of chemical poisoning or other pathological condition. In both cases, it was found possible to determine an average normal blood pressure together with its standard deviation. In both cases, the individual measurements were approximately normally distributed about their means. With both dogs and men, we have measured the systolic and diastolic blood pressures, using the standard cuff and manometer, and determining the appearance, change, and disappearance of sound by means of a stethoscope held over the artery below the blood pressure cuff. Measurements on dogs are made with the animal standing quietly and the cuff over the femoral artery. Measurements on man are made with the subject seated and according to the technique contained in the joint recommendations of the American Heart Association and the Cardiac Society of Great Britain and Ireland (2).

Since each blood pressure measurement on an individual might be considered as a sample from an infinite number of possible measurements during the individual's lifetime, it seemed that the Shewhart (3) control chart technique ought to be applicable. We first tested this technique on dogs before and after exposure to chemicals, charting the diastolic pressure and pulse pressure (systolic minus diastolic).

Dogs offer a suitable test of the method because they can be maintained in a controlled environment on a standard diet and stabilized routine both before, during, and after exposure to a given chemical. The results of a typical experiment in which a dog was exposed to the vapor of trichlorethylene, a degreasing solvent, are shown in Fig. 1. Blood pressure measurements were made twice a day for twenty days before any exposure to trichlorethylene. From these data, the "normal" diastolic pressure and pulse pressure and their respective standard deviations for this particular dog were calculated. The points plotted are the means of groups of four successive measurements, and the statistical limit lines are placed at plus and minus two and three times the standard error of the means. At the end of the control period, exposure of the dog to trichlorethylene vapor six hours a day, five

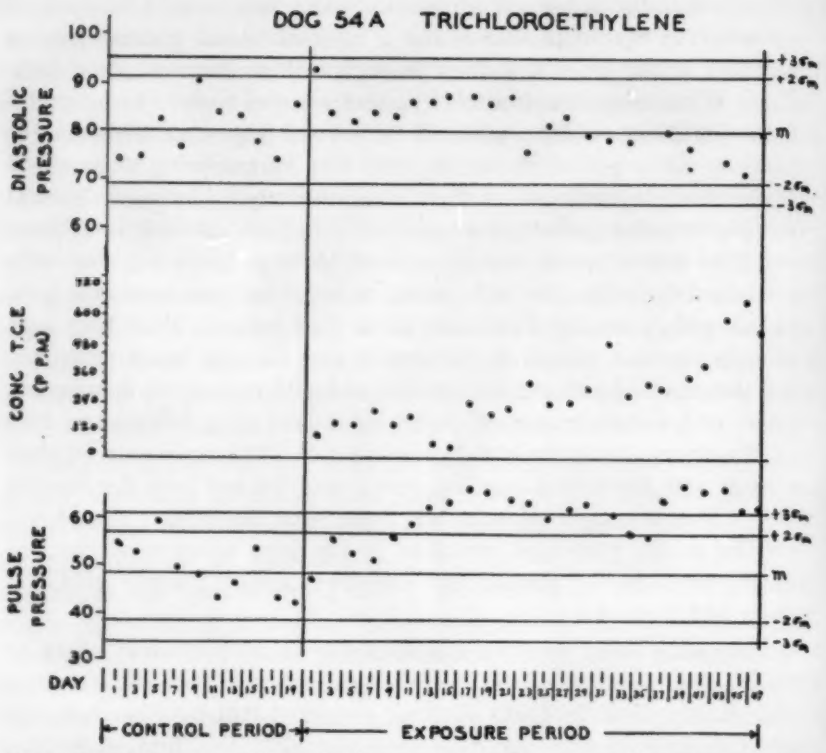


FIG. 1. BLOOD PRESSURE CONTROL CHART — DOG EXPOSED TO TRICHLORETHYLENE

days a week was begun. The average concentration of trichlorethylene over each exposure period, expressed as parts per million (p.p.m.) is shown in the center section of the graph. It can be seen that a statistically significant rise in pulse pressure occurred with exposure to concentrations on the order of 200 p.p.m. As concentrations were increased above 250 p.p.m., a downward trend in diastolic pressure became apparent in addition to the elevated pulse pressure. This dog showed no evidence of clinical illness. We would emphasize that blood pressure changes of the type observed are not specific for trichlorethylene, although by elimination we are justified in attributing them to trichlorethylene in this particular case. Statistically significant changes are always taken to indicate, however, the entrance of an assignable cause of variation which often must be tracked down by investigation. So far as our laboratory dogs are concerned, statistically significant changes

have not been observed to occur as a result of seasonal or other causes unrelated to exposure to chemicals.

It is not to easy to obtain good control chart data for human beings. For one thing, it is not economically feasible to determine the mean and standard deviation for blood pressure on each individual worker before he is exposed to chemicals. Secondly, it is not economically feasible to make blood pressure examinations on workers at very frequent intervals, such as twice daily; in plant practice, observations are usually made once a week, once every two weeks, once a month, or in some cases involving little exposure, at even longer intervals. In the third place, human beings are very susceptible to what might be called extra-curricular influences. Examinations the day after pay-day are quite apt to be abnormal. There are in one plant under our observation several individuals who almost invariably show abnormal blood pressures when examined without previous warning. These same individuals are almost invariably normal if given twenty-four hours advance notice that they will be examined. The reason in these cases for the discrepancy is known to be alcohol and lack of sleep. Fortunately, they are not employed in an occupation involving exposure to a dangerous chemical, or they would have to be taken off their jobs, since they are apparently abnormal more often than not, and in that condition, regardless of its cause, would be abnormally susceptible to the effects of a dangerous chemical.

In order to be able to use control charts for blood pressure on workers, it has been deemed sufficient to employ in exposed operations only those workers who conform to predetermined standards. These standards are derived from the study of the blood pressure examinations of several thousand employees who were in a state of good health as far as could be judged by available criteria. Thus, one fits Cinderella to the shoe, rather than vice versa. One advantage which accrues from this practice, is that the initially abnormal are screened out before there is any possibility of their abnormality being further aggravated or of it making the worker unduly sensitive to the effects of chemicals.

The standard control chart forms which we use for human beings are illustrated in Figs. 2a and 2b. The first form (Fig. 2a) is designed for the control of diastolic pressure, pulse pressure, and the P.P.; D.P. Score. The mean diastolic pressure (79 mm. Hg.) and mean pulse pressure (44 mm. Hg.), as well as the standard deviations (8 mm. Hg. in each case) were derived, as was mentioned, from the study

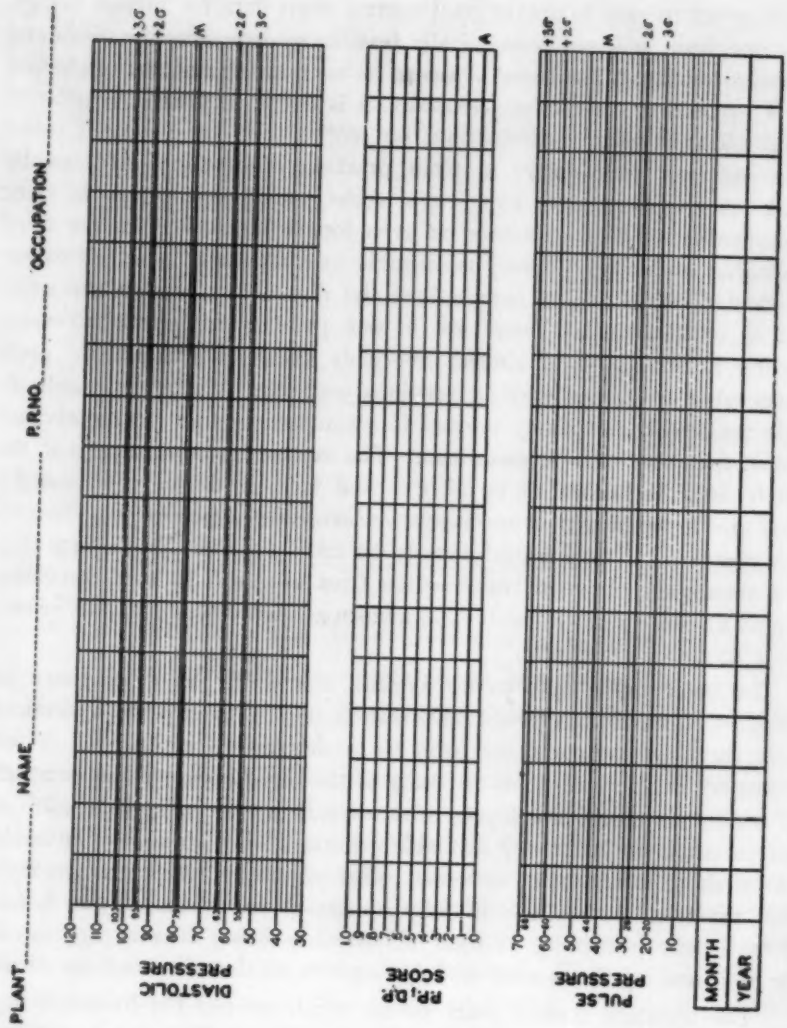


FIG. 2a. FORM FOR BLOOD PRESSURE CONTROL CHART — HUMAN BEINGS

of several thousand examinations of normal workers[1]. Statistical limit lines are placed on the charts for diastolic pressure and pulse pressure at plus and minus two, and three, standard deviations. In the original charts, the 2-sigma lines are colored yellow (warning) and the 3-sigma lines are colored red (danger). The P.P.; D.P. Score, to be explained more fully below, is the probability of obtaining simultaneously deviations in pulse pressure and diastolic pressure from their respective means, the sum of the squares of which are as great as or greater than those actually observed. Only one statistical control limit, placed at score 0.10 is used, and any scores falling on or below this line are considered abnormal. Based on a compound probability, the score responds to variations in either diastolic pressure, pulse pressure, or both.

The control chart form shown in Fig. 2b is similar to that of Fig. 2a, except that a control chart for pulse rate is substituted for the chart for P.P.; D.P. Score. This chart is used when workers are exposed to certain chemicals which have an effect on pulse rate.

On the average, twelve to twenty-four examinations are made on an individual in the course of a year. In view of this small number, it is not practical to combine examinations into subgroups. We realize, that by using single observations, and particularly by using the population means and standard deviations rather than those pertaining directly to the individual, we lose sensitivity in the statistical sense. In consequence, we must pay more attention to trends within the statistical limit lines than might otherwise be the case. This, however, does no harm.

The most usual type of exposure to chemicals is the chronic one in which the amount of exposure is minimal. If, however, the worker is exposed to minimal amounts, forty hours a week, over a period of months, definite toxic effects can occur. In such cases, the control chart usually reflects a definite trend rather than a sudden jump out of control limits. Exposure to larger amounts of chemicals, however, may cause a very prompt shift in blood pressure. Where one is faced with the interpretation of a trend in blood pressure, and is worried about the significance of the trend, it should be possible to apply some of the significance tests developed for detecting lack of randomness in series of runs (4, 5, 6).

Aside from chemical exposure, alcoholic excesses, acute infections, etc., may cause sudden shifts in blood pressure, whereas malnutrition,

[1] Measurements made with the subjects seated.

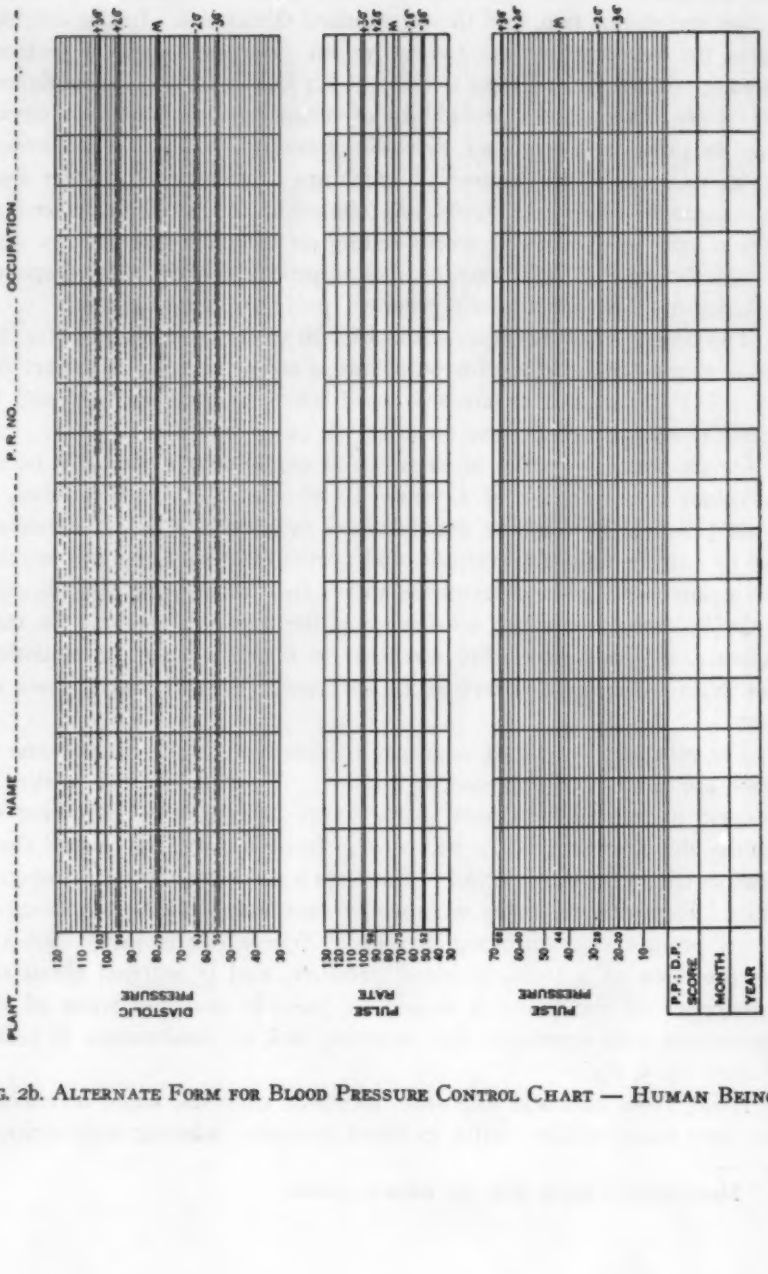


FIG. 2b. ALTERNATE FORM FOR BLOOD PRESSURE CONTROL CHART — HUMAN BEINGS

fatigue, and chronic infections may simulate the type of blood pressure changes observed in chronic minimal exposure to chemicals. The plant physician must, therefore, determine in each case where a trend develops or points suddenly go out of control limits, what has caused the shift. When a non-occupational cause of the aberration is exposed, the worker is referred to his private physician for treatment, and is required to return to the plant physician in a few days for a recheck. Persistent circulatory abnormality on recheck examinations, regardless of its origin, may be sufficient cause for removal of the worker from all chemical exposure until he is fully recovered.

With all their limitations, these control charts have proved to be useful to plant physicians in following the progress of their patients, and give the physician some framework within which he can evaluate the significance of changes as they occur. We might remark again that the plant physician must be cognizant of the effect of exposure on each individual and that it is not sufficient for him to know that, in general, safe procedures and safe standards prevail throughout his plant. The reason for this is that the worker's individual condition, as he meets exposure, determines to a large extent the effect of chemical exposure on him.

The application of a control chart for blood pressure to a worker exposed to the action of organic nitrites is shown in Fig. 3. In this chart, pressures are indicated as vertical lines which show the range of diastolic pressure and pulse pressure measured at two different levels, namely, the fourth phase or "change of sound," and the fifth phase or "disappearance of sound." The magnitude of the spread between these two levels has some significance.

At the end of May, 1937, this worker was shifted to a job in which there was no exposure to nitrites. His next three readings were all within expected limits. At the end of July, the worker returned to a job involving exposure. His next examination revealed a significant drop in diastolic pressure, coupled with a widening of the fourth to fifth phase interval. On the following examination, the diastolic pressure had recovered somewhat, but the pulse pressure had fallen. The October examination showed both low diastolic and low pulse pressure, and the man was removed from exposure. During the next three months, blood pressure measurements were satisfactory, but the worker returned to his old job for one day during the latter part of January. His next blood pressure examination showed a picture very similar

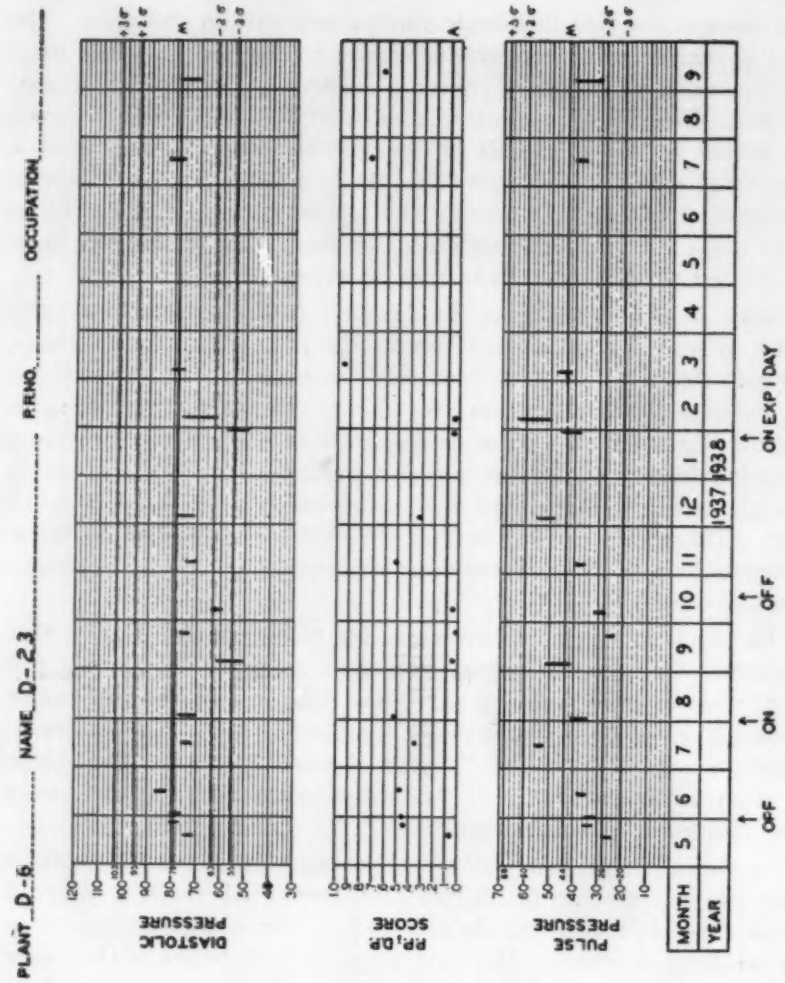


FIG. 3. BLOOD PRESSURE CONTROL CHART — MAN EXPOSED TO ORGANIC NITRITES

to that seen in the first examination in September, 1937. The man then remained permanently away from exposure to nitrites, and following examinations show recovery. The control chart for scores gives a consistent picture. This worker through personal idiosyncrasy, or perhaps through poor work habits, could not work with the nitrites without developing a circulatory abnormality.

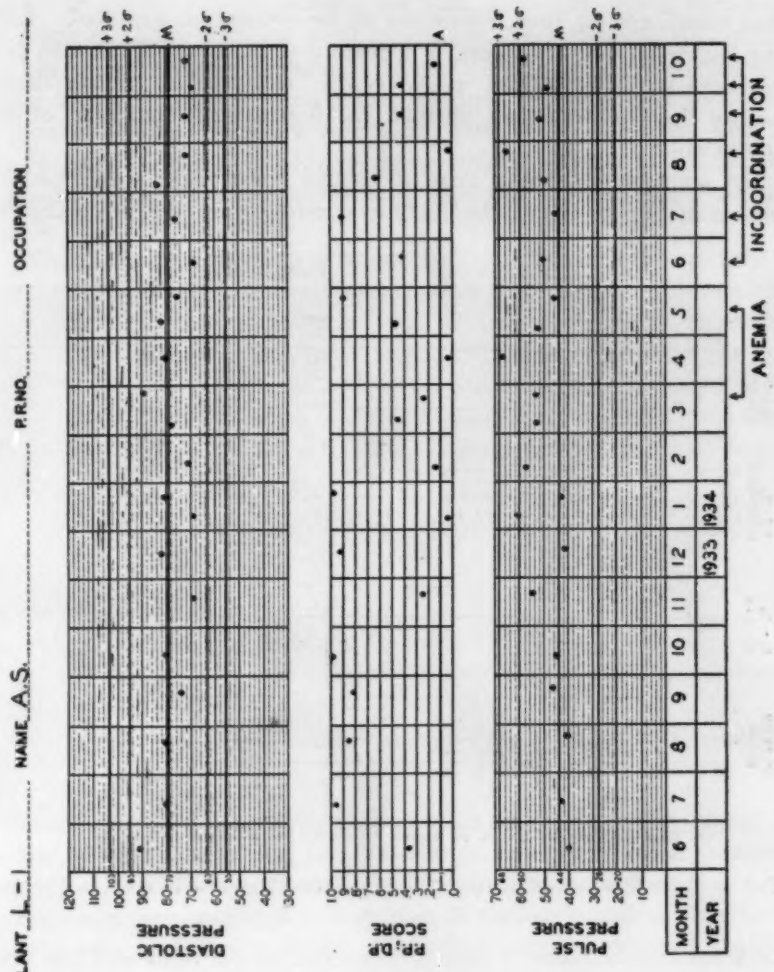


FIG. 4. BLOOD PRESSURE CONTROL CHART — MAN EXPOSED TO ORGANIC AND INORGANIC LEAD

Fig. 4 shows the control chart of a worker exposed to organic and inorganic lead. This worker was hired in June, 1933, and throughout that year showed no particular abnormality. In January, 1934, one high pulse pressure and abnormal score were noted. From January on, elevated pulse pressures prevailed. Toward the end of March, anemia

was noted, and in June, symptoms of incoordination appeared. Looking backward over the chart, it appears that the upward trend in pulse pressure probably started in November, 1933, or about five months before the appearance of anemia, the first specific symptom of lead intoxication.

A somewhat different type of control chart for blood pressure is shown in Fig. 5. Here, the qualities controlled are: (1) the difference

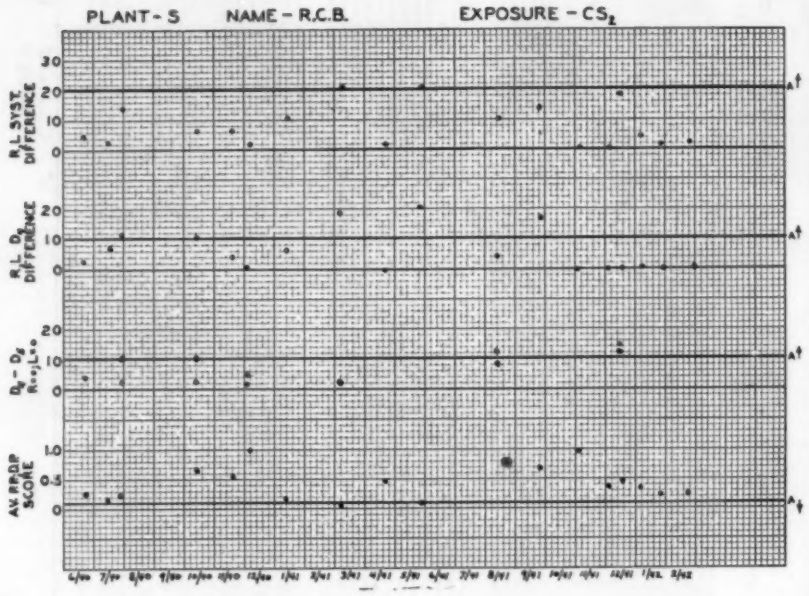


FIG. 5. BLOOD PRESSURE CONTROL CHART — MAN EXPOSED TO CARBON DISULFIDE

between systolic blood pressures measured on the right and left arms; (2) the difference between fourth phase diastolic pressures measured on the right and left arms; (3) the difference between fourth phase and fifth phase diastolic pressures measured on each arm; and (4) the P.P.; D.P. Score. The worker, in this case, was exposed to carbon disulfide, and evidence of circulatory abnormalities appears on each of the four sections of the chart.

It should be remarked that all of the data shown for workers has been taken from medical records in our files, and in no case did the plant physician construct or use these charts at the time of the examina-

tions. It might also be pointed out that, since the living organism possesses an ability to adapt itself to stresses, the functional abnormalities may or may not be corrected, eventually, by one or another compensatory mechanism. We, by no means, maintain that there will always be an abnormal blood pressure *coincident* with frank pathology due to the specific toxic action of a given chemical. The circulatory abnormalities usually occur before such pathology—hence their usefulness in preventive medicine.

While quality control charts for individuals are very useful, it is often desirable to follow group trends rather than individual trends, so that one may get a synoptic view of the condition of an entire plant or of various occupational subgroups within a plant. So far, the P.P.; D.P. Score has proved most useful for this purpose. The use of the P.P.; D.P. Score, which fluctuates with variations in either diastolic pressure, pulse pressure, or both, was first suggested by Foulger (7), who defined the score as

$$\log S = -0.00339\,(x^2 + y^2) \qquad (1)$$

where

S = Score

$\log S$ = logarithm of S to base 10

x = deviation of diastolic pressure from established mean of 79 mm.

y = deviation of pulse pressure from established mean of 44 mm.

The statistical basis for equation (1) is as follows: Let s_x and s_y be the standard deviations for diastolic pressure and pulse pressure, respectively. ($s_x = s_y = 8$ mm. Hg.) Putting $x_i/s_x = t_i$, and $y_i/s_y = u_i$, the compound probability of getting deviations t_i and u_i simultaneously, when both are normally distributed and uncorrelated (which conditions have been found to apply), is given by equation (2).

$$P_{t_i u_i}\,dt\,du = (1/2\pi)e^{-(t_i^2 + u_i^2)/2}\,dt\,du \qquad (2)$$

The probability of getting simultaneously, deviations as great as or greater than t_i and u_i, is

$$P = (1/2\pi)\int_{t_i}^{\infty}\int_{u_i}^{\infty} e^{-(t_i^2 + u_i^2)/2}\,dt\,du \qquad (3)$$

Equation (3) can be integrated readily by substituting for $(t_i^2 + u_i^2)$ its equivalent, χ^2. Then the locus of values of t and u which gives a constant value of χ^2 is a circle of radius χ. Transforming to polar coordinates, (3) can be written

$$P = (1/2\pi) \int_0^{2\pi} \int_\chi^\infty e^{-\chi^2/2} \chi \, d\chi \, d\theta \tag{4}$$

On integration, equation (4) becomes

$$P = e^{-\chi^2/2} = e^{-(t_i^2 + u_i^2)/2} \tag{5}$$

The identity of P and S can be shown by substituting known values in equation (5);

$$t_i = x_i/8$$
$$u_i = y_i/8$$

and therefore,

$$t_i^2 + u_i^2 = (x_i^2 + y_i^2)/64$$

and the exponent of e in equation (5) becomes

$$-(x_i^2 + y_i^2)/128$$

Taking logarithms, equation (5) can be written

$$\log_{10} P = -(0.4343/128)\ (x_i^2 + y_i^2) = -0.00339\ (x_i^2 + y_i^2) \tag{6}$$

which is identical with equation (1) for $\log_{10} S$.

Foulger (7) has published a simple chart for the calculation of the P.P.; D.P. Score from the raw measurements of diastolic pressure and pulse pressure. This chart is reproduced in Fig. 6. On this chart, all scores equal to or less than 0.10 are simply designated "A" (abnormal). The choice of 0.10 as the dividing line between normal and abnormal is, of course, somewhat arbitrary, but has the advantage that a deviation of just over two sigmas in either component of the score, with the other component having zero deviation from its mean, gives an abnormal score. Usually, however, abnormal scores result from deviations of less than two sigmas in both components simultaneously.

From the probability background of the P.P.; D.P. Score, abnormal scores might be expected to occur by chance alone ten times out of a hundred. Foulger (7) found in one group of apparently normal workers that abnormal scores occurred six times out of a hundred. The discrepancy may be due to slightly different means and standard deviations in this group. Accepting, for the moment, that a Score of 0.10 corresponds to a 10 per cent probability, one can calculate that the fre-

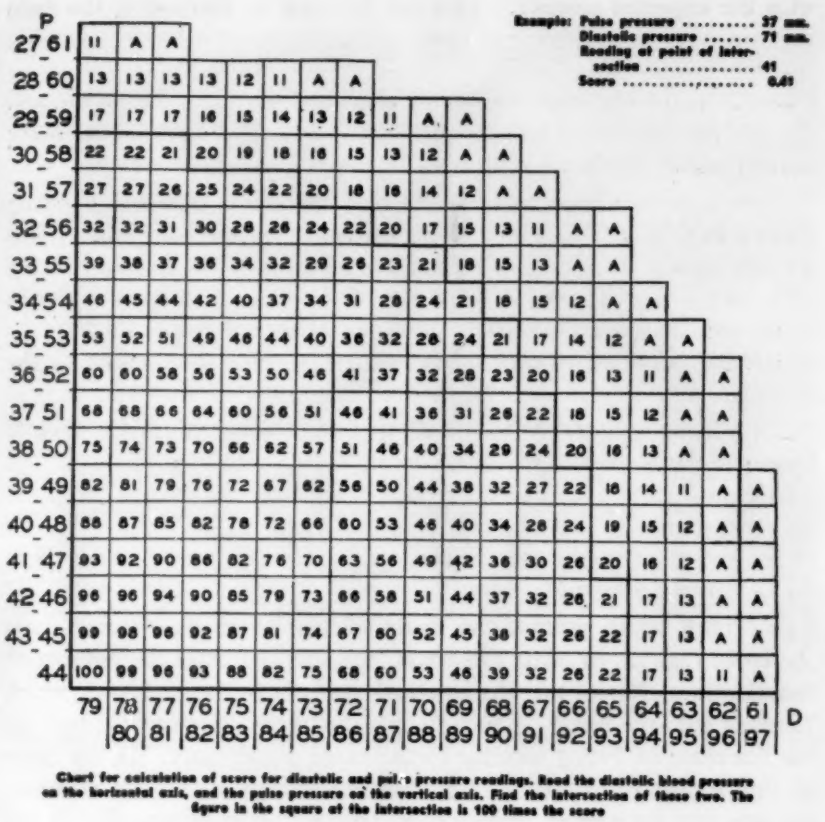

Example: Pulse pressure ..... 37 mm.
Diastolic pressure ..... 71 mm.
Reading at point of intersection 41
Score 0.41
P
D
Chart for calculation of score for diastolic and pulse pressure readings. Read the diastolic blood pressure on the horizontal axis, and the pulse pressure on the vertical axis. Find the intersection of these two. The figure in the square at the intersection is 100 times the score

FIG. 6. CHART FOR CALCULATION OF SCORE FOR DIASTOLIC AND PULSE PRESSURE READINGS

quency distribution of abnormal scores should be given by the binomial expansion

$$(0.90 + 0.10)^N$$

and that the expected number of abnormal scores in a group of N normal examinations should be

$$E_{(A)} = 0.10N$$

Thus, in judging whether or not a given group of N examinations shows too many abnormal scores, one must compare the observed number

with the expected number. This can be done by computing the ratio

$$R = A/E_{(A)} = A/0.10N$$

where A is the observed number of abnormal scores in the group, and $E_{(A)}$ is the expected number, or $0.10N$. $E_{(A)}$ is rounded out to the nearest whole number.

When there is no assignable cause of variation, R should fluctuate about a value of 1.0, sometimes being greater and sometimes less. When a value greater than 1.0 is obtained, the question of significance of the ratio arises. Perhaps the simplest test of significance to apply is one in which the "maximum expected number of abnormal scores for a group of size N" is calculated on the basis of the binomial distribution by the equation

$$A_{max} = E_{(A)} + 2\sqrt{pqN} = 0.10N + 2\sqrt{0.09N} = 0.10N + 0.6\sqrt{N}$$

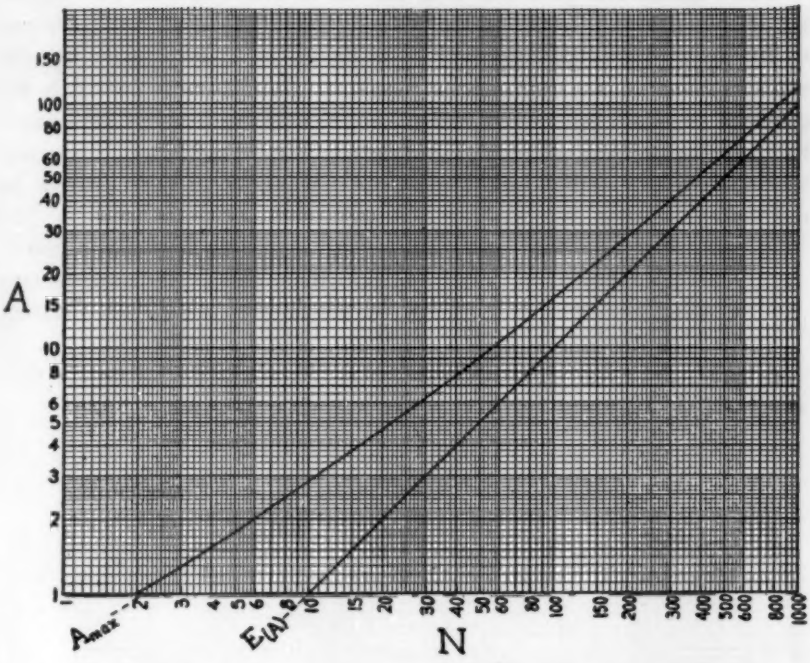
One may then compute the ratio

$$R_m = A/A_{max}$$

If R_m exceeds 1.00, the chances are less than one in twenty that it could do so without assignable cause.

A chart, which permits the ready calculation of $E_{(A)}$ and A_{max} is shown in Fig. 7. In using this chart, one simply locates the number of examinations, N, on the abscissa and then finds the ordinates which intersect with the line $E_{(A)}$ and A_{max}, respectively. Conversely, one can use the chart of Fig. 7 directly for a test of significance. If the point of intersection of N and A, the observed number of abnormal examinations, lies between $E_{(A)}$ and A_{max}, the degree of abnormality is not statistically significant at the 2.5 per cent level. If the point of intersection lies to the left of line A_{max}, the degree of abnormality is significant at the 2.5 per cent level.

In order to obtain a valid estimate of the degree of abnormality in a given group of examinations, each man in the group should have either one, or an equal number of examinations. This situation is not usually met with in industrial practice, however, because men who show abnormal scores are, and should be, examined more frequently than those who show normal scores. Consequently, the total number of examinations in a given time period are apt to be overweighted with abnormals. Foulger (7) has suggested a way of overcoming the difficulty by a method of subdividing the ratio of the observed number of abnormal scores to the maximum expected number into several



1) Locate the point of intersection on the chart of N, the number of men examined during a given time period, and A, the number of men showing abnormal scores on first examination during the time period.

2) If the group is normal, the points of intersection should fluctuate around the line $E_{(A)}$ on the chart. If a point of intersection lies to the left of line A_{max} there is an excessive amount of abnormality within the group examined.

3) Take as a new group, those men who were abnormal at first examination and are re-examined during the given time period. Repeat the steps under (1) with this group. If the point of intersection of N and A again lies to the left of A_{max} it is evidence of *persistent* abnormality within the group re-examined.

4) The time period chosen should be that in which every member of the group under the study is examined at least once.

FIG. 7. SIGNIFICANCE CHART FOR A ABNORMAL SCORES IN N EXAMINATIONS

components. Being somewhat impressed with the simplicity and utility of the control chart for individuals, we have attempted to extend the control chart technique so that it might be used for following the group trend of abnormal blood pressure scores in a given plant over a period of time.

There are several problems with respect to control charts for following plant trends in blood pressure scores. In the first place, the size of the group examined may vary from month to month. Secondly, the statistical limits vary with different group size. Finally, there is the question of treating a group which is overloaded with abnormal examinations due to re-examination of individuals who showed abnormal scores on first examination. It seemed that these problems might be overcome by using the following scheme:

(1) For each time period in which every man in the group is usually examined at least once, calculate the percentage of *men* showing abnormal P.P.; D.P. Scores on *first* examination during the time period.

(2) Plot this percentage on the control chart against the time period (Fig. 8).

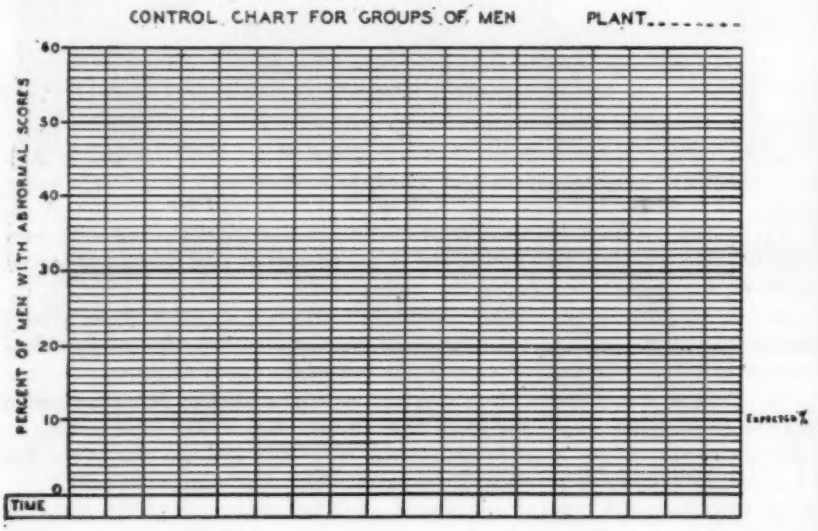


FIG. 8. FORM FOR CONTROL CHART FOR BLOOD PRESSURE SCORES OF GROUPS OF MEN

(3) Sketch in, for the given time period, the upper two-sigma control line. The percentage of abnormal examinations corresponding to 10 per cent plus two standard deviations, is readily obtained by reference to the chart shown in Fig. 9. In using this chart, one simply locates the group size (number of men in the group) on the ordinate, and finds the abscissa which corres-

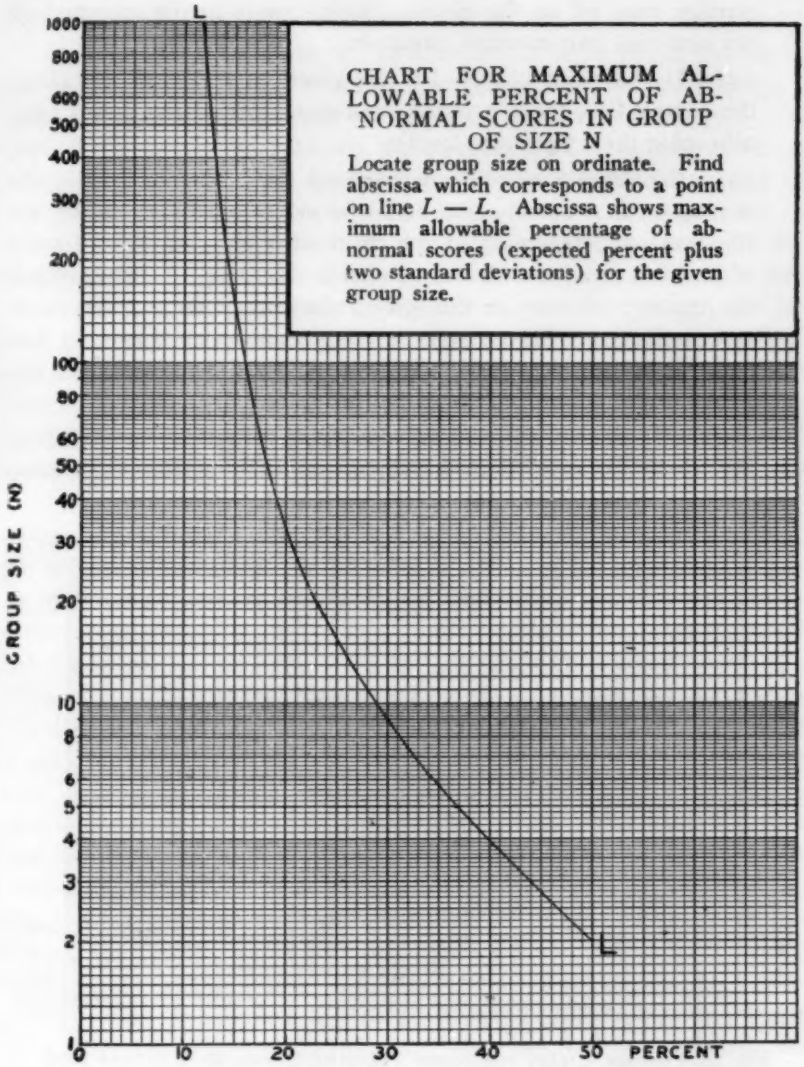


FIG. 9. CHART FOR MAXIMUM ALLOWABLE PERCENTAGE OF ABNORMAL SCORES IN GROUPS OF SIZE *N*

ponds to a point on line *L-L* for the given ordinate. The percentage read off on the abscissa, corresponds to the expected 10 per cent plus two standard deviations.

(4) If the point plotted for the given time period lies above the control line, there is excessive abnormality in the group (significant at the 2.5 per cent level).

(5) Construct a new group from all those men who were abnormal on first examination and who are re-examined during the time period. Referring to the chart of Fig. 7, locate the point of intersection of the number of men in the group re-examined and the number of men in this group showing abnormal scores on re-examination. If the point of intersection lies above the line A_{max}, it is evidence that there is persistent abnormality in this group.

A control chart constructed on the above principles is shown in Fig. 10. Only one point, that for July, 1946, lies outside the control

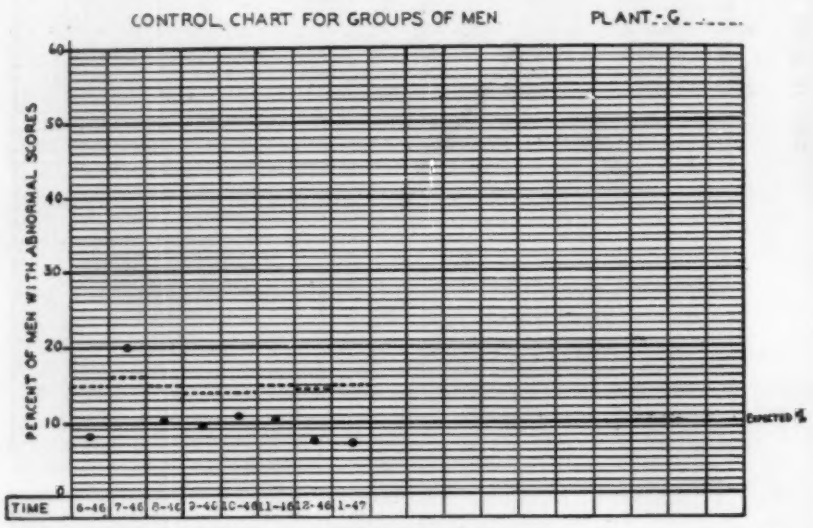


FIG. 10. CONTROL CHART FOR BLOOD PRESSURE SCORES OF WORKERS FROM A PARTICULAR PLANT

limits. When the criterion outlined under (5), above, was applied, evidence of persistent abnormality in the group was obtained. As a result, several men were removed from exposure on orders of the plant

physician, and in subsequent months there was no indication of excessive abnormality in this plant.

Suppose that the warning given when points begin to fall outside the limit lines of the control chart is disregarded, no corrective action is taken, and the abnormal men are allowed to remain on the job. The control charts will have served their primary purpose, and could not be expected to contribute much more. The probability of getting abnormal scores, for example, would no longer be 0.10. So far as the abnormal individuals are concerned, three things might happen: (1) they might improve spontaneously if the conditions responsible for their abnormality no longer obtain; (2) they might show a spurious improvement so far as blood pressure is concerned, by virtue of physiological adaptation; and (3) the abnormality of some individuals might become perpetuated because, in their abnormal state, they may be more susceptible than usual to a variety of causative factors, such as further chemical exposure, infections, fatigue, malnutrition, and so on.

In 1920, Greenwood and Yule (8) published a paper on the nature of frequency distributions representative of multiple happenings with particular reference to the occurrence of multiple attacks of disease or of repeated accidents. They first tested to determine whether the occurrence of such multiple events could be the result of pure chance, the frequencies being predictable by the binomial or Poisson distributions. It was found that these distributions did not adequately describe the data obtained from a study of the occurrence of multiple accidents among workers in war plants which was carried out by Greenwood and Woods (9). There appeared to be an unequal susceptibility to accidents among different individuals. Greenwood and Yule suggested that the most reasonable hypothesis would be that one's chances of sustaining an accident would be increased if one had had a previous accident. Thus, if each individual in the group had an initial probability of sustaining an accident, p_0, the probability of sustaining a second accident would be p_1, that of a third accident p_2, etc., where $p_2 > p_1 > p_0$. They did not succeed in finding a general distribution based on these postulates which could be used in practice. They did find that a distribution based on the concept of unequal but fixed liabilities among individuals of the group gave a satisfactory approximation to the observed data. This distribution is approximated by a negative binomial distribution, according to which the frequencies of 0, 1, 2, . . . etc., accidents are given by successive terms of the following expansion:

$$N\left(\frac{c}{c+1}\right)^r\left\{1+\frac{r}{c+1}+\frac{r(r+1)}{2!(c+1)^2}+\frac{r(r+1)(r+2)}{3!(c+1)^3}\ldots+\right.$$

where N is the number of persons involved, $r/c = M$ and $\mu_2 = r(c+1)/c^2$, M being the mean, and μ_2 the second moment about the mean of the distribution. Greenwood and Yule called this distribution the "Unequal Distribution."

Subsequent workers have suggested other distributions which may apply equally well or better to the type of data studied by Greenwood and Woods (9). As a matter of interest, however, we applied the Greenwood and Yule distribution to a study of the medical records of 83 individuals from a certain plant in which blood pressures were measured 10 to 12 times on each individual over a six months' period. Men who showed abnormal blood pressure scores were not removed from exposure to chemicals and no general program of corrective action was taken. The occurrence of 0, 1, 2, 3, ..., 8+ abnormal examinations in individuals of the groups is shown in Table 1. The calculated

TABLE 1

Frequency of abnormal examinations

NUMBER OF ABNORMAL EXAMINATIONS	FREQUENCY OBSERVED	FREQUENCY CALCULATED	
		Chance (Poisson) Distribution	Unequal Distribution
0	28	16	27
1	21	27	22
2	14	22	15
3	8	12	9
4	4	5	5
5	5	2	3
6	1	0	2
7	1	0	1
8+	1	0	0
Total	83	84	84

frequencies on the basis of the Poisson distribution and Greenwood and Yule's negative binomial distribution (Unequal Distribution) are also shown for comparison. It is apparent that the Poisson frequencies

do not fit the data whereas the Unequal Distribution gives an excellent approximation.

It is at least interesting that the distribution of circulatory abnormalities in an industrial plant follows the distribution of multiple accidents in similar plants. It would be tempting to speculate that there might be some causal relationship between the occurrence of accidents and the occurrence of circulatory abnormalities. It would not be unreasonable to suspect that a man who was suffering from a circulatory disturbance might be more liable to the types of human failure which lead to accidents than a man in normal health. We do not have the data on which to test this hypothesis, however. We do feel that it would be worth studying because at the present time most emphasis on accident prevention has been placed on the avoidance of individual carelessness, whereas it may be that carelessness is often a consequence of a remediable physiological abnormality.

DISCUSSION

While the emphasis in the preceding discussion has been on studies of the blood pressure, it should be pointed out that we do not consider such studies to be all-sufficient. We chose to follow the blood pressure of workers because both previous experience and theoretical considerations indicated that it might be a fruitful thing to follow for the purpose of detecting the beginnings of functional disturbances due to the action of a great variety of toxic chemicals. It is quite conceivable, however, that there might be cases in which there would be no profit in studying variations in the blood pressure, and in which control charts for other bodily attributes might be appropriate.

Our main point of emphasis is that useful information for a program of industrial preventive medicine can be obtained through the application of statistical techniques to the study of human beings. By the use of such techniques, it is usually possible for the plant physician to detect the beginning effects of industrial exposure to toxic chemicals, and to detect them before such drastic changes in the structural or functional components of the organism occur as to impair, even temporarily, the ability of the individual to live and work effectively. Consequently, he can recommend corrective action which makes it possible to carry out a program of *preventive* medicine rather than one of diagnosis and treatment of pathological conditions.

We do not imply that an abnormal blood pressure is a specific

indication of exposure to chemicals. It is an indication of a circulatory disturbance which may arise from the action of chemicals, or may be entirely non-occupational in origin. The physician must decide on the basis of investigation, whether or not chemical exposure is involved.

SUMMARY AND CONCLUSIONS

Workers in industries handling or manufacturing chemicals may be exposed to the action of a great variety of chemicals, the physiological effects of many of which may be relatively unknown. Industrial preventive medicine attempts to *prevent* deterioration in the health of the workers which might result from such occupational toxicological hazards.

Statistical methods are discussed which aid the industrial physician in detecting the first mild warnings of the toxic action, if any, of industrial chemicals upon the workers. On the basis of these warnings, an investigation into the causes of the physiological changes can be made, and corrective action taken, before frank chemical poisoning or serious deterioration of health takes place.

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RELATIVE GROWTH OF THE LIMB SEGMENTS AND TAIL IN *ATELES GEOFFROYI* AND *CEBUS CAPUCINUS*

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INTRODUCTION

IN A previous study on macaques (Lumer and Schultz, 1941), it was shown that the growth of the limb segments and tail in relation to the trunk and to one another conforms to the law of allometry

$$y = bx^a,$$

in which x and y are the sizes of two parts, and b and a are constants. It was further shown that the application of this law led to certain significant conclusions, both from the developmental and systematic points of view, which were not readily disclosed by such methods as the use of size indices.

The present paper presents a similar analysis of relative growth in two species of platyrrhine monkeys, *Ateles geoffroyi* and *Cebue capucinus*. As in the preceding investigation, the data were supplied by the second of the two authors, while the first is responsible for the analysis and conclusions.

MATERIALS AND METHODS

The data consist of measurements on 113 specimens of *A. geoffroyi*, including 9 fetuses, and 37 specimens of *C. capucinus*, including 2 fetuses. All were shot in the wild state, the great majority in the vicinity of Chiriqui, Panama, and the rest in a single locality in Eastern Nicaragua. They, therefore, constitute fairly homogeneous groups.

All measurements were made externally on fresh specimens. The measuring techniques employed are described in full by Schultz (1929).

Since the exact ages are not known, the individuals were grouped into developmental stages based on the state of the dentition. The average measurements for each stage are presented in Table 1.

In *A. geoffroyi,* relative growth was investigated in both the prenatal and postnatal stages, but in *C. capucinus* the number of fetuses it too small to permit any analysis of prenatal relative growth. For the purpose of analysis, the data were seriated according to trunk height, as shown in Table 2, which gives the average measurements for successive size groups. Because of the small number of specimens, the fetuses of *A. geoffroyi* were not grouped. Postnatal relative growth in *A. geoffroyi* was analyzed in males and females separately; however, for reasons to be given below, they have been lumped together here.

One serious shortcoming of the data is the relatively small number, not only of fetuses, but also of infant and juvenile specimens in the sample. In fact, the majority of individuals in both species fall within two size classes in the adult range. Such a preponderance of adults is virtually unavoidable, however, in view of the methods by which this type of material is collected.

The lengths of each of the limb segments, as well as upper limb length (upper arm + forearm + hand lengths), lower limb length thigh length + knee height), and tail length, were plotted against trunk height on a double logarithmic grid. Straight lines were fitted to these plots by the regression method of least squares (see Feldstein and Hersh, 1935a, also Reeve, 1940). The slopes and *y*-intercepts of these lines give the values of a and $\log b$ respectively in the allometric equation above. Standard errors of the constants were computed by the methods described by Feldstein and Hersh (1935b) and Lerner (1936).

RESULTS

The relative growth curves for *A. geoffroyi* are shown in Fig. 1. In every case, a distinct jog occurs at about the time of birth, so that separate lines are required to fit the prenatal and postnatal stages. The values for newborn specimens generally fall between the two lines and are therefore not included in either one.

On the whole, the points on the curves conform fairly well to the fitted lines, although the postnatal stages show more or less distinct signs of systematic curvature. This is true especially of the hand / trunk relation, where the entire set of points can as readily be inter-

TABLE 1

Average lengths in millimeters of trunk, limb segments, and tail in fetal, newborn, infantile, juvenile, and adult stages of Ateles geoffroyi and Cebus capucinus

The infantile stage is terminated by the completion of the deciduous dentition and the juvenile by the completion of the permanent dentition.

NUMBER OF SPECIMENS	AGE	TRUNK HEIGHT	RANGE OF VARIATION	THIGH LENGTH	KNEE HEIGHT	LEG LENGTH	FOOT LENGTH	UPPER ARM LENGTH	FOREARM LENGTH	HAND LENGTH	TAIL LENGTH
				A. geoffroyi							
9	Fetus	76.1	22.3 — 102	44.4	46.6	40.6	50.1	47.9	42.9	39.6	185.4
3	Newborn	102.7	100 — 106	67.2	69.7	61.3	74.3	72.0	65.0	58.3	304.0
8	Infantile	123.1	106 — 138	87.9	93.3	82.3	94.4	92.1	85.8	72.4	398.4
16	Juvenile	215.7	173 — 249	139.3	148.6	132.2	141.8	146.6	142.4	114.5	598.9
50	Adult ♀	301.8	258 — 340	194.8	203.1	182.9	174.2	199.6	202.0	141.7	757.2
27	Adult ♂	289.9	229 — 324	187.8	196.9	178.1	170.3	193.4	196.3	137.7	724.4
77	Adult ♂ and ♀	297.6	229 — 340	192.3	200.9	181.5	172.8	197.6	200.0	140.3	745.7
				C. capucinus							
2	Fetus	48.8	47 — 50.5	27.5	28.5	24.7	31.0	27.5	24.0	21.0	98.5
1	Newborn	102.0	———	53.5	58.5	51.5	62.0	52.0	44.0	39.0	225.0
2	Infantile	139.5	129 — 150	83.0	89.0	78.5	88.5	69.0	63.8	54.0	352.5
7	Juvenile	205.9	178 — 233	122.0	126.0	113.6	118.1	98.6	91.1	74.1	435.7
11	Adult ♀	233.7	198 — 246	133.5	142.0	126.3	122.5	109.5	104.8	78.6	466.4
14	Adult ♂	251.6	219 — 285	144.1	150.4	135.4	130.6	115.9	112.1	83.1	482.6
25	Adult ♂ and ♀	243.8	198 — 285	139.4	146.7	131.4	127.0	113.1	108.9	81.2	475.5

TABLE 2

Average lengths of the limb segments and the tail with increasing trunk height (all in mm.) in A. geoffroyi and C. capucinus

NUMBER OF SPECIMENS	TRUNK HEIGHT	THIGH LENGTH	KNEE HEIGHT	LEG LENGTH	FOOT LENGTH	UPPER ARM LENGTH	FOREARM LENGTH	HAND LENGTH	TAIL LENGTH
				A. geoffroyi (Prenatal stages)					
1	22.3	13.0	12.2	11.1	11.0	16.0	11.8	10.5	40.0
1	52.0	31.0	30.0	26.2	30.0	35.0	31.0	24.0	110.0
1	68.0	38.0	40.0	35.0	44.0	42.5	39.0	35.0	158.0
1	75.0	45.0	47.0	40.0	48.0	48.0	44.0	41.0	175.0
1	75.0	43.5	46.0	40.0	47.0	46.0	43.0	39.0	166.0
1	91.0	57.5	60.5	54.0	69.0	61.5	53.5	54.0	242.0
1	97.0	57.0	61.0	53.0	68.0	60.5	54.0	51.0	244.0
1	103.0	55.0	61.0	52.0	64.0	59.0	54.0	48.5	254.0
1	102.0	60.0	62.0	54.0	70.0	62.5	62.5	55.5	280.0
				A. geoffroyi (Postnatal stages)					
3	109.7	74.5	79.0	69.3	80.5	78.5	70.9	61.7	344.7
3	125.7	86.7	93.0	81.3	93.0	90.7	84.3	71.0	388.7
2	170.5	119.5	128.0	109.5	122.5	120.5	117.0	97.0	515.0
3	189.0	120.3	129.7	116.3	130.3	133.3	126.0	106.0	531.3
2	212.5	138.5	148.0	130.5	140.0	149.0	143.0	113.0	598.0
8	231.4	154.0	162.6	145.0	152.1	160.3	157.0	122.4	648.5
5	250.8	169.5	178.5	158.5	157.5	173.3	172.5	128.5	704.0
5	272.0	182.2	191.0	172.2	166.2	187.6	190.2	132.6	717.0
28	291.5	191.3	199.1	180.1	171.0	196.8	198.7	138.6	734.3
35	307.8	194.9	203.8	183.9	175.5	199.5	202.9	142.9	757.6
4	324.8	198.0	208.5	186.8	177.0	205.5	208.0	146.5	751.8
1	340.0	208.0	220.0	199.0	187.0	217.0	220.0	151.0	796.0
				C. capucinus (Postnatal stages)					
1	129.0	80.0	84.0	75.0	81.0	66.0	59.5	52.0	355.0
1	150.0	86.0	94.0	82.0	96.0	72.0	68.0	56.0	350.0
1	178.0	103.0	112.0	99.0	110.0	86.0	82.0	65.0	417.0
3	195.0	120.7	124.0	112.0	118.7	98.0	92.0	74.0	443.7
4	210.5	128.3	133.8	120.3	120.3	105.5	98.5	78.3	450.8
7	232.4	137.7	142.9	128.6	125.9	110.6	104.4	79.6	469.0
13	246.5	140.0	146.8	131.2	125.9	113.1	109.0	80.5	466.6
3	271.3	144.0	153.7	138.0	132.7	115.3	112.0	84.3	507.0
1	285.0	146.0	160.0	143.0	139.0	125.0	125.0	90.0	516.0

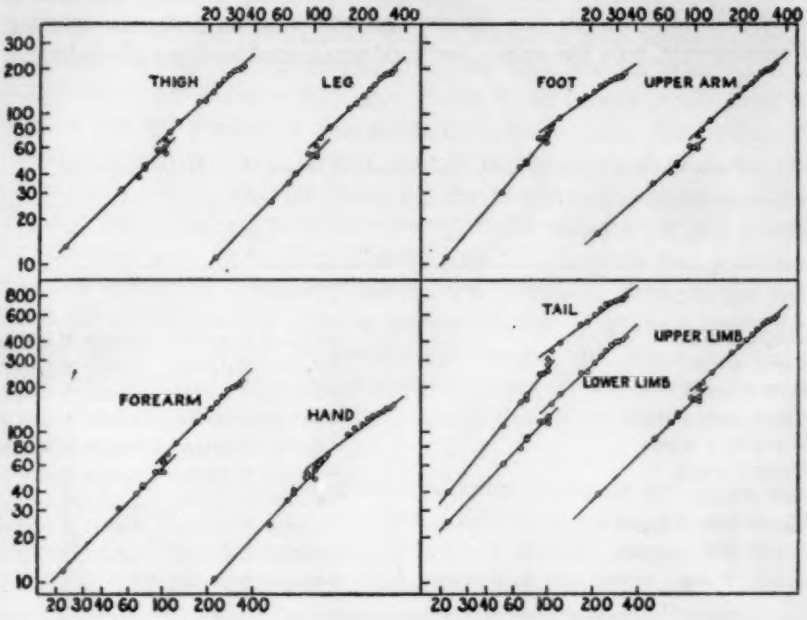

FIG. 1. DOUBLE LOGARITHMIC PLOT OF THE LENGTHS OF THE LIMB SEGMENTS, UPPER AND LOWER LIMBS, AND TAIL AGAINST TRUNK HEIGHT IN *Ateles geoffroyi*

preted as falling along a single curved line, and to an almost equal degree of the foot / trunk and tail / trunk relations. Such systematic curvature may very likely indicate a real deviation from the law of allometry. At the same time, it may be due to the small number of specimens in the younger stages. The greater deviations displayed by the hand, foot, and tail may perhaps arise from the fact that these measurements each correspond to the length of a series of bones rather than to the length of a single bone, as do the measurements of the remaining limb segments, although it should be recognized that this is true also of trunk height. In any event, the application of the equation can be justified empirically, on the grounds that the observed and calculated values of y generally differ only slightly. Even in the hand / trunk relation, the most extreme deviation is not more than 8 per cent off.

The values of the constants log b and a for these curves are given in Table 3. For the postnatal stages, they were originally computed separately for males and females. It was found, however, that in no

case were there any significant differences, that is, that there are no sexual differences in the relative growth of the parts in question. Consequently, only the values for both sexes combined are given here.

TABLE 3

Values of log b and α, with their standard errors, for Ateles geoffroyi

RELATION	log b	α
	Prenatal stages	
Thigh / trunk	−0.2232 ± 0.0689	0.9944 ± 0.0364
Leg / trunk	−0.3849 ± 0.0665	1.0581 ± 0.0365
Foot / trunk	−0.6075 ± 0.0872	1.2222 ± 0.0469
Upper arm / trunk	0.0032 ± 0.0609	0.8926 ± 0.0327
Forearm / trunk	−0.2740 ± 0.0725	1.0133 ± 0.0364
Hand / trunk	−0.4440 ± 0.0322	1.0834 ± 0.0548
Tail / trunk	−0.0928 ± 0.0668	1.2497 ± 0.0360
Upper limb / trunk	0.2593 ± 0.0402	0.9865 ± 0.0346
Lower limb / trunk	−0.0010 ± 0.0325	1.0412 ± 0.0311
Thigh + leg / upper arm + forearm	−0.6502 ± 0.0546	1.0168 ± 0.0283
	Postnatal stages	
Thigh / trunk	0.0090 ± 0.0220	0.9191 ± 0.0093
Leg / trunk	−0.0389 ± 0.0183	0.9282 ± 0.0081
Foot / trunk	0.5084 ± 0.0226	0.6996 ± 0.0096
Upper arm / trunk	0.1028 ± 0.0120	0.8861 ± 0.0081
Forearm / trunk	−0.1638 ± 0.0157	0.9960 ± 0.0087
Hand / trunk	0.2821 ± 0.0348	0.7505 ± 0.0135
Tail / trunk	1.0811 ± 0.0264	0.7244 ± 0.0095
Upper limb / trunk	0.5308 ± 0.0198	0.8893 ± 0.0098
Lower limb / trunk	0.3551 ± 0.0215	0.9049 ± 0.0087
Thigh + leg / upper arm + forearm	0.0193 ± 0.0091	0.9821 ± 0.0036

The values of α for the prenatal stages, with the exception of those for the thigh and upper arm, are greater than one, whereas the postnatal values are all less than one. In every case, the postnatal value is less than the corresponding prenatal value. The differences are not all statistically significant; nevertheless, the consistency with which they occur suggests that they are real. In other words, the results indicate that the average percentage growth rates of the limb segments and tail

in relation to that of the trunk show a drop after the time of birth.

In the prenatal stages, a is highest in the distal limb segments (hand and foot) and falls off proximally. After birth, on the other hand, a is highest in the forearm and leg. Hence there occurs at the time of birth a marked change in the growth gradients along the limbs. It may be noted that the postnatal values for the leg and thigh do not differ significantly, whereas those for the forearm and upper arm do. What is particularly noticeable, however, is the sharp drop in a shown by the hand and foot. The gradients in the forelimb and hindlimb are thus essentially alike, and the general homology between the two limbs apparently extends also to the distribution of growth intensities within them. It should be recognized, though, that these gradients, which are derived from average measurements, do not necessarily represent the gradients as they exist in every individual (see Lumer and Schultz, 1941).

The values of a for the upper and lower limbs do not differ significantly, either before or after birth. But these results are apt to be misleading. The two measurements are not strictly comparable, since lower limb length does not include the length of the foot. Unfortunately, it is impossible to obtain comparable measurements from those given, for the sum of thigh, leg, and foot lengths is not equal to the length of the lower limb.

A somewhat clearer picture can perhaps be obtained by examining the constants for the thigh + leg / upper arm + forearm relation. In this case, neither the prenatal nor postnatal values of a are significantly different from unity or from each other. Hence it can be said that at least these portions of the upper and lower limbs have about the same percentage growth rates in relation to the trunk throughout life. If the hand and foot are considered separately, it will be seen that the latter has a significantly higher value of a than the former prenatally and a significantly lower value postnatally. Yet the inclusion of the hand in the upper limb length does not greatly affect the result, and it appears likely that at most only a slight antero-posterior gradient exists in the relative growth of the limbs as a whole.

Up to the time of birth, the tail exhibits a higher relative growth rate than any of the limb segments. Afterwards, its growth falls off sharply, and the length of the tail in relation to the trunk decreases markedly throughout postnatal life.

In *C. capucinus,* the sample is too small to permit any separation of males and females. The relative growth curves for both sexes combined are shown in Fig. 2. Here there is no doubt that the data do not conform to the law of allometry, the majority of the curves being distinctly sigmoid in appearance. Although in most cases the deviations of the calculated from the observed values of y are not large, it is clear that fitting the equation to these data can be justified on empirical grounds only as giving an indication of a general trend. The constant a in this case represents only the average value of the ratio of percentage growth rates during postnatal life. For this reason, although the values of log b and a were determined (see Table 4), their standard errors were not computed. A more precise analysis of the trends in the growth ratios would require a larger sample.

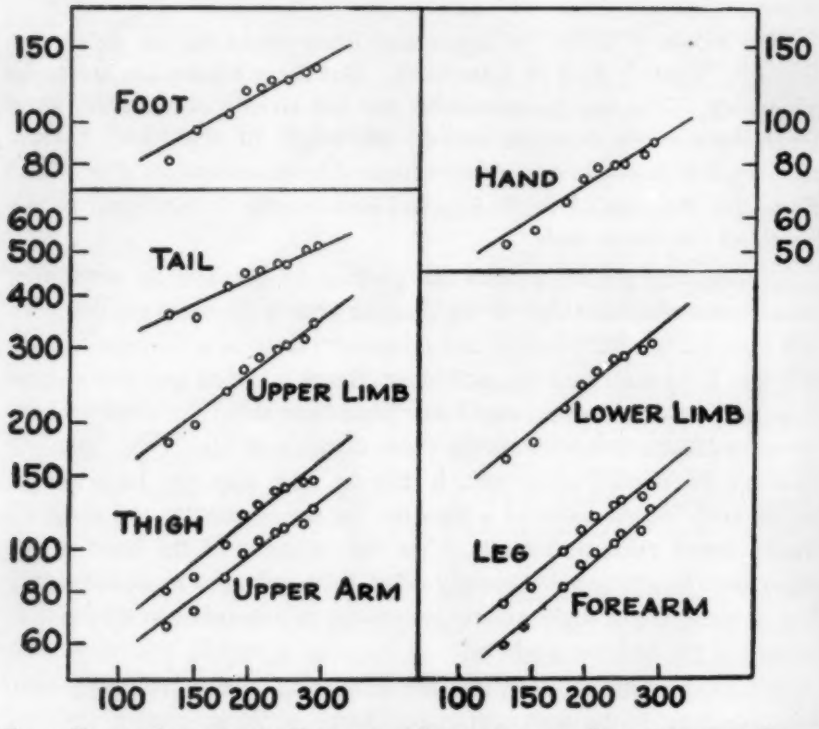

FIG. 2. DOUBLE LOGARITHMIC PLOT OF THE LENGTHS OF THE LIMB SEGMENTS, UPPER AND LOWER LIMBS, AND TAIL AGAINST TRUNK HEIGHT IN *Cebus capucinus*

TABLE 4

Values of log b and a for Cebus capucinus

RELATION	log b	a
Thigh / trunk	0.2216	0.8052
Leg / trunk	0.1622	0.8191
Foot / trunk	0.7885	0.5515
Upper arm / trunk	0.2244	0.7656
Forearm / trunk	—0.0096	0.8560
Hand / trunk	0.4338	0.6182
Tail / trunk	1.5852	0.4568
Upper limb / trunk	0.6740	0.7566
Lower limb / trunk	0.5306	0.8063
Thigh + leg / upper arm + forearm	0.0653	1.0096

A comparison of these values of a with the corresponding values for *A. geoffroyi* discloses immediately that the present ones are all considerably lower. At the same time, the values of log b are uniformly higher. This last is misleading, however, for the constant b represents the length of a particular part at a trunk height of one millimeter, which is an enormous and completely unwarranted extrapolation beyond the range of the data to which the curves were fitted.

A more accurate basis of comparison is offered by the measurements given in Table 1 for newborn specimens. These show that for the same value of trunk height, the limb segments and tail are all appreciably shorter in *C. capucinus* than in *A. geoffroyi*. Hence these structures exhibit not only a lower postnatal relative growth rate in *C. capucinus*, but a smaller initial size as well.

Nevertheless, it may be seen that there is a similarity in the growth patterns of the two species. In particular, the growth gradients within the limbs are alike. Moreover, the value of a for the thigh + leg / upper arm + forearm relation is very close to unity in both species. It is important to note that such underlying similarities in growth gradients may exist even though the actual proportions are different.

DISCUSSION

Of the two forms dealt with in the present investigation, *Ateles* is exceptional among platyrrhine monkeys with respect to the relative

length of the arms. Elliot (1913, Vol. II, p. 21) characterizes the genus as "the most highly developed arboreal animal of the New World monkeys." Schultz (1930) remarks that while the average brachial and intermembral indices for platyrrhine monkeys are 94.9 and 87.6 respectively, those of *Ateles* are both over 100. *Cebus*, on the other hand, is a much more typical genus.

We have seen that despite these differences in proportions there exists an underlying similarity in the distribution of growth intensities in these forms. It is of interest to determine to what degree this similarity extends to other groups. Among the catarrhine monkeys, comparable data are available only for macaques (Lumer and Schultz, 1941). The most extensive data are for *Macaca mulatta*, and since the relative growth of the limb segments varies only slightly in different species of macaques, we may take this species as representative of the genus.

Like *A. geoffroyi*, *M. mulatta* shows an abrupt drop at birth in the growth ratios of both the limb segments and the tail, the prenatal values of α being markedly greater than one and the postnatal values all less than one. In fact, the drop is in every instance greater than in *A. geoffroyi*.

With reference to the gradients within the limbs in *M. mulatta*, Lumer and Schultz (1941, p. 291) state:

> "In the upper limb, the value of α during prenatal development is highest for the hand and lowest for the upper arm. There exists, therefore, a growth gradient extending along the axis of the limb, with the point of the highest growth intensity located in the hand. In postnatal life, the relative growth rates of the upper arm and forearm are approximately equal, and are considerably higher than that of the hand, which exhibits at birth a much greater decrease in the value of α than do the other upper limb segments. The growth pattern in the lower limb completely parallels that in the upper, both before and after birth."

It is clear from this description that there is a close resemblance between the growth gradients of *M. mulatta* and those of *A. geoffroyi* and *C. capucinus*. The only marked difference is that in the last two forms the postnatal value of α for the forearm is significantly higher than that for the upper arm. These resemblances may also be seen in Fig. 3, in which the growth gradients are depicted.

It is worth noting that the occurrence of growth centers in the distal limb segments is associated with high growth ratios for the limbs as a whole. With the falling off of these growth ratios, the growth

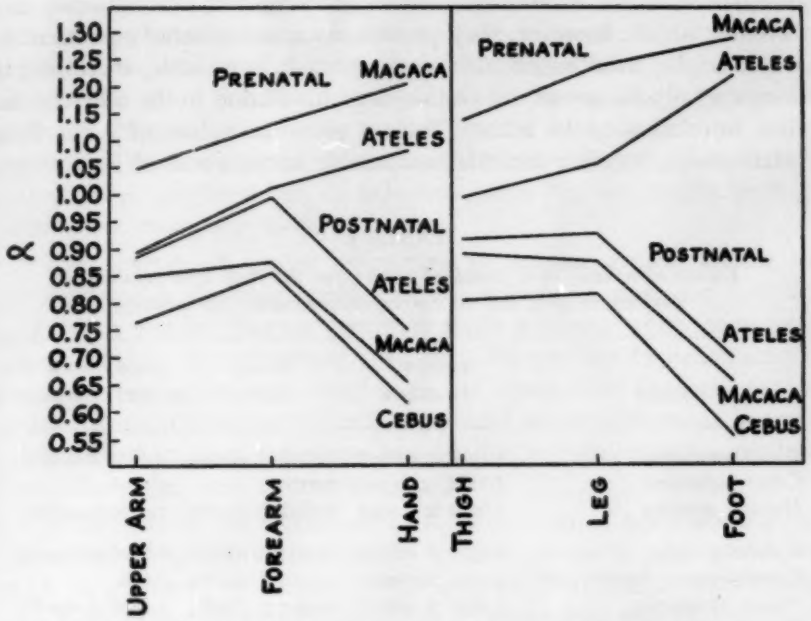

FIG. 3. THE GROWTH GRADIENTS IN THE UPPER AND LOWER LIMBS OF *Ateles geoffroyi, Cebus capucinus,* AND *Macaca mulatta*

centers are shifted proximally. This phenomenon, as Reeve and Huxley (1945) point out, is of rather general occurrence.

With respect to the relative growth of the two limbs, a small but distinct difference exists. In *M. mulatta,* both the prenatal and postnatal values of a for the thigh + leg / upper arm + forearm relation are significantly higher than one, which is not true of the present forms. In *A. geoffroyi,* the postnatal value is slightly less than one. In this connection, it may be noted that *M. mulatta* has an adult intermembral index of 88.2 as compared to 106.4 in *A. geoffroyi. C. capucinus,* on the other hand, has an index of only 82.7. Similarly, the brachial indices in the three species are 96.0, 101.2, and 96.2, and the crural indices are 90.8, 94.3, and 94.3 respectively. It is evident that in adult limb proportions *M. mulatta* shows a much closer resemblance to *C. capucinus* than to *A. geoffroyi.*

Relative growth of the limb segments in the anthropoid apes has been investigated by Lumer (1939) on the basis of measurements of the long bones. Such skeletal measurements have been shown to be directly

comparable to the external measurements employed here (Lumer and Schultz, 1941); however, they provide no measurements equivalent to trunk height, hand length, or foot length. It is possible, therefore, to compare only the growth of one segment in relation to the other or one limb in relation to the other. Table 5 gives the values of a for these relationships, together with the comparable values obtained in monkeys.

TABLE 5

Values of a, with their standard errors, for the limb bone relations in anthropoid apes, and the corresponding values for monkeys

SPECIES	RADIUS / HUMERUS	TIBIA / FEMUR	TIBIA + FEMUR / RADIUS + HUMERUS
Ateles geoffroyi	1.1240 ± 0.0037	1.0099 ± 0.0050	0.9821 ± 0.0036
Cebus capucinus	1.1181	1.0160	1.0096
Macaca mulatta	1.0292 ± 0.0079	0.9837 ± 0.0105	1.0120 ± 0.0045
Hylobates spp.	1.0573 ± 0.0222	1.0104 ± 0.0165	0.8626 ± 0.0202
Symphalangus syndactylus	1.0573 ± 0.0222	1.0104 ± 0.0165	0.918
Pongo pygmaeus	1.0830 ± 0.0057	0.9905 ± 0.0085	1.0086 ± 0.0061
Pan sp.	0.9952 ± 0.0112	1.0174 ± 0.0092	1.0070 ± 0.0114
Gorilla gorilla	0.9781 ± 0.0099	0.9574 ± 0.0065	1.0459 ± 0.0049

As the table shows, in the gibbons and the siamang the postnatal values of a for the radius / humerus and tibia / femur relations are both approximately equal to unity. The same is true of the chimpanzee. The orang-utan differs in that a for the first of these relations is slightly but significantly greater than one, while in the gorilla both values are distinctly less than one. For the tibia + femur against radius + humerus, the gibbons and siamang have values of a considerably less than one, the orang-utan and chimpanzee about one, and the gorilla slightly greater than one.

With regard to these growth ratios, the three species of monkeys most closely resemble the orang-utan. This, again, does not mean that they are the most similar in adult proportions. According to Schultz (1937), the orang-utan has the highest intermembral index of all the anthropoid apes with the exception of the siamang. At the same time, it resembles the monkeys more closely in intralimb proportions than do any of the others.

No effort has been made to interpret or compare the values of log *b*. Although variations in initial size are of great importance, this constant, for the reason given above, is of no value as an index of initial size differences. For this purpose it would be necessary to use the sizes of the parts in question at the time of birth or at some other equivalent landmark of the onset of a particular growth period. Since, except in *A. geoffroyi* and *C. capucinus*, such data are totally lacking, it has been impossible to do so.

The absence of sexual differences in relative growth shown by *A. geoffroyi* is also characteristic of *M. mulatta* (Lumer and Schultz, 1941). A similar absence occurs in those relations which have been investigated in the anthropoid apes, with the possible exception of the lower limb / upper limb relation in the orang-utan (Lumer, 1939). Schultz (1937) found statistically significant sexual differences in some adult indices in man, but these may be due to differences in absolute body size rather than in relative growth.

Differences in the magnitude of a for a series of parts are a manifestation of spatial differences in growth intensity, giving rise to a set of gradients or a basic growth pattern. Within the framework of a given pattern of growth, variations in proportions may arise through variations in absolute body size, in times of onset of growth, or in relative growth rates, without altering the character of the growth gradients. The foregoing results suggest that with respect to the limb segments, the basic pattern is the same in both platyrrhine and catarrhine monkeys, while the differences which appear in the anthropoid apes, particularly the gorilla, involve an alteration of the pattern itself.

There are also indications that the abrupt change in the growth ratios at the time of birth is a general phenomenon. As Lumer and Schultz (1941) have pointed out, it occurs also in man. In this case, however, it could not be determined whether it is accompanied by a shifting of growth centers within the limbs. The available data are too meager to permit any investigation of such changes in the anthropoid apes.

These conclusions are, of course, highly tentative. To test their validity adequately would require a much broader study, embracing a wide range of genera and species, and including much more extensive data on prenatal relative growth. It would also be necessary to investigate relative growth in individuals, in order to determine to what extent

individual variations in growth pattern occur. Such data are difficult to secure.

SUMMARY

The relative growth of the limb segments and tail in *Ateles geoffroyi* conforms fairly well to the law of allometry $y = bx^a$, but in *Cebus capucinus* the equation provides only a rough approximation to the data. In *A. geoffoyi,* these structures as a rule grow more rapidly than the trunk before birth and less rapidly after birth. The drop is greatest in the hand, foot, and tail. Both limbs show a growth gradient with the high point in the distal segment prenatally and in the forearm and leg postnatally. The upper and lower limbs grow at about the same rate in relation to the trunk throughout life. There are no sexual differences. In *C. capucinus* the limb segments and tail are relatively shorter at birth and grow less rapidly in relation to the trunk postnatally than in *A. geoffroyi,* but the growth gradients are the same in character. The growth pattern of the limbs in these forms resembles that in the macaques, and comes closest to that of the orang-utan among the anthropoid apes. The results suggest that variations in proportions among both platyrrhine and catarrhine monkeys arise through variations in relative growth occurring within the framework of a common growth pattern.

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HEIGHT AND WEIGHT OF OTTAWA ELEMENTARY SCHOOL CHILDREN OF TWO SOCIO-ECONOMIC STRATA*

BY J. W. HOPKINS †

INTRODUCTION

THE significant increases recorded during the present century in average height and weight at specific ages of children and young adults of the white race living on the North American continent are well known, Meredith and Meredith (10), for example, reporting that the typical Toronto school child aged 9 years was no less than 3 inches taller in 1939 than in 1892. It may be, as suggested by Huntington (6), that all operative causes are not yet known, and that there is possibly some differential fertility of the taller genotypes. Nevertheless, it is widely considered that improvements in nutrition and in general environmental conditions have been major factors in this trend.

In this event, one would expect to observe inequalities in the average size of individuals drawn from different economic strata of a population at the same time, according as these individuals were more or less favoured in respect of food and living conditions. More than 20 years ago Baldwin (1) stated that the results of all investigations then reported agreed in demonstrating that this was so. More recent studies such as those of Jenss (7) in New York, Hardy, Boyle and Newcomb (5) in Chicago, Keyfitz (8) in Toronto, and LeRiche (9) in Pretoria also support this view, although the first of these authors emphasizes the necessity of distinguishing between the effects of economic status and of racial origin, which are often associated in their operation. Wolff (14) has further reported short-term oscillations in the growth in different calendar years of children of specified ages and social status,

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due in part no doubt to variations in nutrition occasioned by economic conditions, but in his opinion possibly also ascribable to some extent to fluctuations in factors such as sunshine and temperature. Shuttleworth (12) has likewise commented on the occurrence of "good" and "bad" growing years for girls in the United States.

In the present paper, records of the height and weight of children attending certain Ottawa elementary schools during the years 1933 to 1945 are analyzed statistically. The results are indicative of some slight increase in size even in this short period. More significant differentials were however linked with socio-economic status, and these are shown to have persisted under the supposedly more favourable conditions resulting from wartime economic activity. It is hoped that parallel studies may subsequently be undertaken in other parts of Canada.

DATA

The Ottawa Public School Board made available for study the accumulated measurements of standing height and weight recorded at the annual examination of all children by the Board's medical staff. From this large body of data a sample was extracted comprising boys and girls aged 6 to 12 years attending six of the elementary schools administered by the Board during each of the periods 1933-35, 1938-40 and 1940-45 [1]. Attendance at all the schools was on a geographical basis, and three of the foregoing six were designated by officers of the Board as drawing children from predominantly better-class residential districts, while the other three were for the most part attended by pupils from less prosperous areas of the city. There was of course considerable intra-school variation, but in the aggregate the socio-economic status of the first group, in which business, professional and administrative classes predominated, was definitely above-average, while that of the second, which included many children of artisans, tradespeople and government employees of the clerical grades, was on the whole below-average.

Standing height (without shoes) was recorded to the nearest 1/10 inch and weight to the nearest 1/4 pound. The total sample comprised 5,233 children, 2,565 boys and 2,668 girls, of whom 2,886 attended

[1] The first of these periods was characterized by economic depression, the second by accelerated activity associated with the outbreak of World War II, and the third coincided with the most intense phase of that conflict.

the better-class and 2,347 the poorer-class schools. The number in any ultimate classification by age, sex, socio-economic group and period fluctuated somewhat, but averaged about 70. Racially, the sample was relatively homogeneous. There is a considerable French-Canadian school population in Ottawa, but this, with few exceptions, attends Separate Schools, and in order to avoid possible complications from hereditary differences in physique, records of the few individuals of this race encountered in the present study were excluded from the sample. This was the only form of individual selection operative. From the last available census figures it was estimated that more than 85 per cent of the children considered here were of ultimate British extraction, with those of English and Scotch ancestry in the majority, as a large proportion of those of Irish descent also attend Separate Schools, the total enrolment of which slightly exceeds that of the Ottawa Public Schools.

ANALYSIS

Average height and weight

The averages of height and weight of boys and girls, with the standard deviation of each appended, are listed in Tables 1 to 4.

A certain amount of irregular variation, within the expected range of random sampling, is to be observed but in general, the girls (Table 2) were about a quarter of an inch taller than boys of the same ages. Furthermore, during the 10-year period the average height of girls recorded for the age groups considered increased by rather less and rather more than half an inch in the more and less favoured socio-economic groups respectively. Some tendency for the height of boys also to increase may be detected in Table 1, but the increments were smaller than those for girls, and for the most part not of conclusive statistical significance. On the other hand, a significant differential in height between the two socio-economic groups, averaging about 1 1/3 inches, was in evidence throughout the period in both boys and girls of all six age groups.

The average weight of both boys and girls of the more favoured group was about 1 1/2 pounds greater in both the 1938-40 and 1943-45 than in the 1933-35 samples. A similar increase is also to be noted in the average weight of the less favoured children, but apparently only after a time lag of several years, as it is to be observed in the records of the 1943-45 but not in those of the 1938-40 sample. Children of

TABLE 1

Average height (in.) of Ottawa elementary school girls classified according to age, socio-economic status and calendar year

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Average height (in.) of Ottawa elementary school girls classified according to age, socio-economic status and calendar year

AGE IN YEARS	ABOVE-AVERAGE SOCIO-ECONOMIC STATUS				BELOW-AVERAGE SOCIO-ECONOMIC STATUS			
	1933–35	1938–40	1943–45	Average	1933–35	1938–40	1943–45	Average
6–7	46.8	46.8	46.8	46.8 ± 0.1	45.4	45.6	46.1	45.7 ± 0.1
7–8	48.6	48.2	48.5	48.4 ± 0.1	47.7	47.8	46.9	47.5 ± 0.2
8–9	50.5	51.3	51.1	50.9 ± 0.1	50.0	49.2	49.8	49.7 ± 0.2
9–10	52.8	53.1	53.1	53.0 ± 0.2	51.4	52.0	52.3	51.9 ± 0.2
10–11	54.4	55.5	54.7	54.9 ± 0.2	53.6	53.6	53.6	53.6 ± 0.2
11–12	56.4	56.9	56.4	56.6 ± 0.2	54.6	55.0	55.1	54.9 ± 0.2
Average	51.6 ± 0.1	51.9 ± 0.1	51.8 ± 0.1	51.8 ± 0.1	50.4 ± 0.1	50.5 ± 0.1	50.6 ± 0.1	50.5 ± 0.1

TABLE 2

Average height (in.) of Ottawa elementary school girls classified according to age, socio-economic status and calendar year

AGE IN YEARS	ABOVE-AVERAGE SOCIO-ECONOMIC STATUS				BELOW-AVERAGE SOCIO-ECONOMIC STATUS			
	1933–35	1938–40	1943–45	Average	1933–35	1938–40	1943–45	Average
6–7	46.7	46.7	46.9	46.8 ± 0.1	44.8	45.5	46.1	45.5 ± 0.1
7–8	48.4	48.2	48.3	48.3 ± 0.1	47.0	46.9	47.6	47.2 ± 0.2
8–9	50.5	50.4	50.5	50.5 ± 0.2	49.0	48.9	49.2	49.1 ± 0.2
9–10	52.3	53.1	52.8	52.7 ± 0.2	50.6	51.4	51.9	51.3 ± 0.2
10–11	54.0	55.4	54.9	54.8 ± 0.2	53.1	53.4	53.7	53.4 ± 0.2
11–12	56.3	56.1	56.6	56.3 ± 0.2	55.0	54.2	55.0	54.7 ± 0.2
Average	51.3 ± 0.1	51.7 ± 0.1	51.7 ± 0.1	51.6 ± 0.1	49.9 ± 0.1	50.1 ± 0.1	50.6 ± 0.1	50.2 ± 0.1

TABLE 3

Average weight (lb.) of Ottawa elementary school boys classified according to age, socio-economic status and calendar year

AGE IN YEARS	ABOVE-AVERAGE SOCIO-ECONOMIC STATUS				BELOW-AVERAGE SOCIO-ECONOMIC STATUS			
	1933–35	1938–40	1943–45	Average	1933–35	1938–40	1943–45	Average
6–7	50.2	51.1	50.0	50.4 ± 0.4	46.0	46.6	48.2	46.9 ± 0.4
7–8	53.5	52.7	53.5	53.2 ± 0.4	51.4	51.6	51.7	51.6 ± 0.5
8–9	58.0	61.3	61.4	60.3 ± 0.5	57.2	54.2	56.8	56.1 ± 0.5
9–10	64.3	66.8	67.4	66.1 ± 0.6	60.5	64.0	64.0	62.8 ± 0.6
10–11	72.5	73.7	72.2	72.8 ± 0.7	67.8	67.4	68.6	67.9 ± 0.6
11–12	77.4	80.8	79.6	79.3 ± 0.7	71.5	73.8	76.0	73.8 ± 0.8
Average	62.6 ± 0.4	64.4 ± 0.4	64.0 ± 0.4	63.7 ± 0.2	59.1 ± 0.4	59.6 ± 0.5	60.9 ± 0.4	59.8 ± 0.2

TABLE 4

Average weight (lb.) of Ottawa elementary school girls classified according to age, socio-economic status and calendar year

AGE IN YEARS	ABOVE-AVERAGE SOCIO-ECONOMIC STATUS				BELOW-AVERAGE SOCIO-ECONOMIC STATUS			
	1933–35	1938–40	1943–45	Average	1933–35	1938–40	1943–45	Average
6–7	48.1	48.9	50.0	49.0 ± 0.4	43.3	46.0	47.8	45.7 ± 0.3
7–8	52.6	51.0	53.8	52.4 ± 0.5	47.5	47.7	51.1	48.8 ± 0.5
8–9	58.5	59.8	60.1	59.5 ± 0.7	53.8	53.7	56.1	54.5 ± 0.7
9–10	65.3	66.9	65.5	65.9 ± 0.7	57.6	59.9	62.5	60.0 ± 0.6
10–11	69.3	75.1	72.7	72.4 ± 0.7	66.8	66.3	69.7	67.6 ± 0.8
11–12	77.9	78.3	80.2	78.8 ± 0.9	71.9	68.3	71.5	70.6 ± 1.0
Average	61.9 ± 0.5	63.3 ± 0.5	63.7 ± 0.4	63.0 ± 0.3	56.8 ± 0.5	57.0 ± 0.5	59.8 ± 0.5	57.9 ± 0.3

the more favoured group were throughout significantly heavier at all ages, the average difference in 1943-45 still amounting to between 3 and 4 pounds.

For the most part the averages in Tables 1-4 are somewhat above those recorded by Keyfitz (8) for Toronto, or by O'Brien, Girshick and Hunt (11) for American children. Both of these groups, however, contained racial elements present in the Ottawa sample in much smaller proportions, if at all. On the other hand, the averages for even the more favoured Ottawa group are significantly below those reported by Simmons and Todd (13) for Cleveland children drawn from a "select and highly cooperative class" of "superior or at least secure economic position."

Variance of height and weight

The variability in height and weight of children of the same age and socio-economic group showed no consistent trend over the period. Table 5 therefore lists the average standard deviations computed from

TABLE 5

Average standard deviation in height (in.) and weight (lb.) of individual Ottawa elementary school children classified according to socio-economic status, age and sex

AGE IN YEARS	ABOVE-AVERAGE SOCIO-ECONOMIC STATUS				BELOW-AVERAGE SOCIO-ECONOMIC STATUS			
	Height		Weight		Height		Weight	
	Boys	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*
6–7	1.9	1.9	6.5	6.8	2.0	1.8	5.5	5.2
7–8	2.0	2.0	6.8	7.3	2.2	2.3	6.1	6.9
8–9	2.2	2.3	7.9	9.7	2.4	2.4	6.9	8.7
9–10	2.3	2.5	9.1	11.0	2.5	2.3	8.5	8.6
10–11	2.4	2.6	11.0	11.8	2.6	2.7	9.1	12.3
11–12	2.5	2.7	11.3	13.7	2.6	2.3	11.8	11.9

all three quinquennial samples, each entry in this table consequently representing the records of about 200 individuals. Variability in both height and weight increased progressively with age. There was no pronounced difference in this respect between children of the same

age of either sex or socio-economic group, as far as height was concerned. Variability in weight, however, was in general greater in girls than in boys of the same age, and in the more prosperous than in the less prosperous group.

Although, as noted, variability increased with age and with economic well-being, calculation of Fisher's indices g_1 and g_2 of symmetry and kurtosis (4) was not indicative of any significant difference in the character of the frequency distribution of individual heights or weights within the various age, sex, and economic categories. That of height was sensibly Gaussian, with mean g_1 for all categories of 0.11 ± .10 and mean g_2 of 0.21 ± .17. In children of the same age, sex, and socio-economic group, therefore, deviations of the same extent above and below the average height at the time occurred with about equal frequency. The intra-category distribution of individual weights on the other hand was positively skewed, leptokurtic and somewhat irregular, with a mean g_1 of 0.84 ± .10 and g_2 of 1.37 ± .17, indicating that even within the same category, children markedly above and slightly below average weight were respectively more numerous than those markedly below and slightly above. This is in agreement with the findings of O'Brien and co-workers (11) in their analysis of the weights of 147,000 boys and girls in the United States. However, these investigators also reported a small but statistically significant departure from the Gaussian form in the frequency distribution of height. Their tests of significance were, of course, more sensitive in proportion to the much larger numbers involved, but the mean g_1 and g_2 reported by them were also somewhat higher, presumably because of the more heterogeneous composition of their sample.

Aggregate frequency distributions of height and weight of all categories of children in units of the standard deviation (grouping interval, 0.25 s.d.) are illustrated in Figs. 1 and 2, the weight distribution being graduated only approximately by the Pearson Type VI curve (3) shown in the latter. The quartiles of this distribution were computed to lie at 0.71 s.d. above and below the mean.

Correlation of height and weight

Although the height and weight of individuals may vary to some extent independently, nevertheless in any sizable group the taller children will on the average be heavier than the shorter ones. A comparative numerical investigation of this trend of weight with height in the children of each sex, socio-economic and period category considered

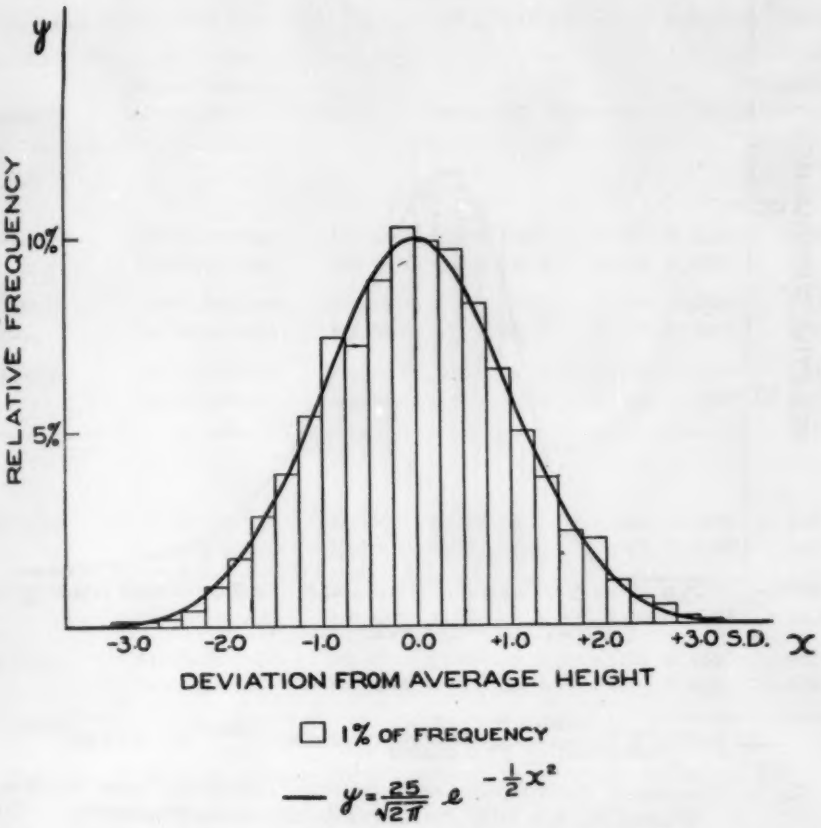

FIG. 1. FREQUENCY DISTRIBUTION OF INDIVIDUAL DEVIATIONS FROM AVERAGE HEIGHT FOR AGE, SEX, PERIOD AND SOCIO-ECONOMIC GROUP

Observed frequencies represented by vertical columns, graduated frequencies by continuous curve. Unit of grouping, 0.25 s.d.

above was accordingly made. In view of the well known exponential relation of weight to height (2) the variables actually correlated were the logarithms of these quantities, values being found by the Method of Least Squares (4) for the regression coefficient b in the equation

$$\log w = a + b \log h \pm \epsilon$$

relating logarithmic height h in inches and weight w in pounds, and

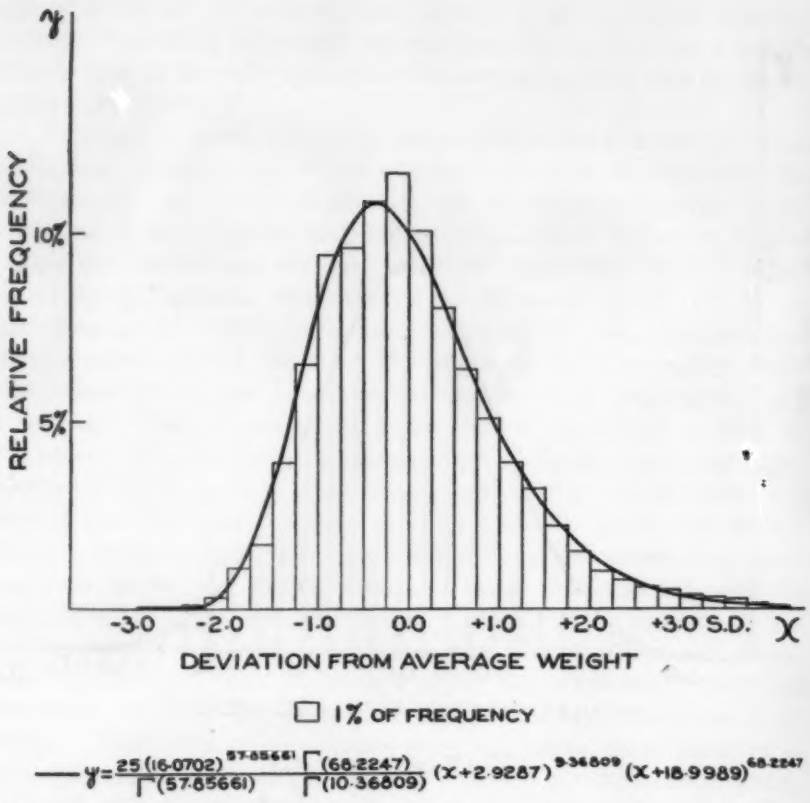

FIG. 2. FREQUENCY DISTRIBUTION OF INDIVIDUAL DEVIATIONS FROM AVERAGE WEIGHT FOR AGE, SEX, PERIOD AND SOCIO-ECONOMIC GROUP

Observed frequencies represented by vertical columns, graduated frequencies by continuous curve. Unit of grouping, 0.25 s.d.

minimizing the sum of ϵ^2 for the children of each classification, irrespective of age. The results of these calculations are summarized in Table 6 and illustrated in Figs. 3, 4, and 5.

The logarithmic regression coefficients listed in Table 6 fall, for the most part, within the range 2.2 to 2.5, showing that in these groups of children, weight increased on the average in the ratio of rather more than the square but less than the cube of height. Appropriate tests (4) resulted in the demonstration of slight but statistically significant differences in the average height-weight relation characterizing

TABLE 6

Correlation of logarithms of height (h, in.) and weight (w, lb.) of individual children

PERIOD	SOCIO-ECONOMIC STATUS	REGRESSION EQUATION	CORRELATION COFFICIENT
		Boys	
1933-34-35	Above-average	$\log w = 2.3783 \log h - 2.2802 \pm .0334$	0.92
	Below-average	$\log w = 2.2225 \log h - 2.0187 \pm .0352$	0.91
1938-39-40	Above-average	$\log w = 2.3723 \log h - 2.2666 \pm .0360$	0.93
	Below-average	$\log w = 2.3195 \log h - 2.1813 \pm .0371$	0.91
1943-44-45	Above-average	$\log w = 2.4760 \log h - 2.4438 \pm .0372$	0.91
	Below-average	$\log w = 2.3000 \log h - 2.1436 \pm .0378$	0.90
		Girls	
1933-34-35	Above-average	$\log w = 2.5178 \log h - 2.5223 \pm .0430$	0.90
	Below-average	$\log w = 2.4871 \log h - 2.4672 \pm .0385$	0.91
1938-39-40	Above-average	$\log w = 2.4896 \log h - 2.4735 \pm .0443$	0.91
	Below-average	$\log w = 2.2789 \log h - 2.1220 \pm .0371$	0.90
1943-44-45	Above-average	$\log w = 2.5178 \log h - 2.5165 \pm .0438$	0.89
	Below-average	$\log w = 2.3395 \log h - 2.2166 \pm .0454$	0.87

children of the two socio-economic groups in all three periods. These are depicted for boys and girls respectively in Figs. 3 and 4. The effect of these differentials was that while at heights above about 4 feet better-class children tended on the average to be slightly heavier than poorer children of the same height, for smaller statures this trend was, if anything, slightly reversed. Although the statistical significance of this apparent reversal is, in most cases, questionable, such a phenomenon would be consistent with the observations of LeRiche (9) who noted in the youngest of his age groups a tendency for the children of poorer parents to be heavier than those of the well-to-do, and suggested that possibly the greater proportion of carbohydrates in the diet of the former produced fatter and more flabby children, heavier than well-fed ones at the earlier ages. It has already been mentioned that in the Ottawa children any inter-group difference of this nature was slight and demonstrable only on a statistical basis. That this was

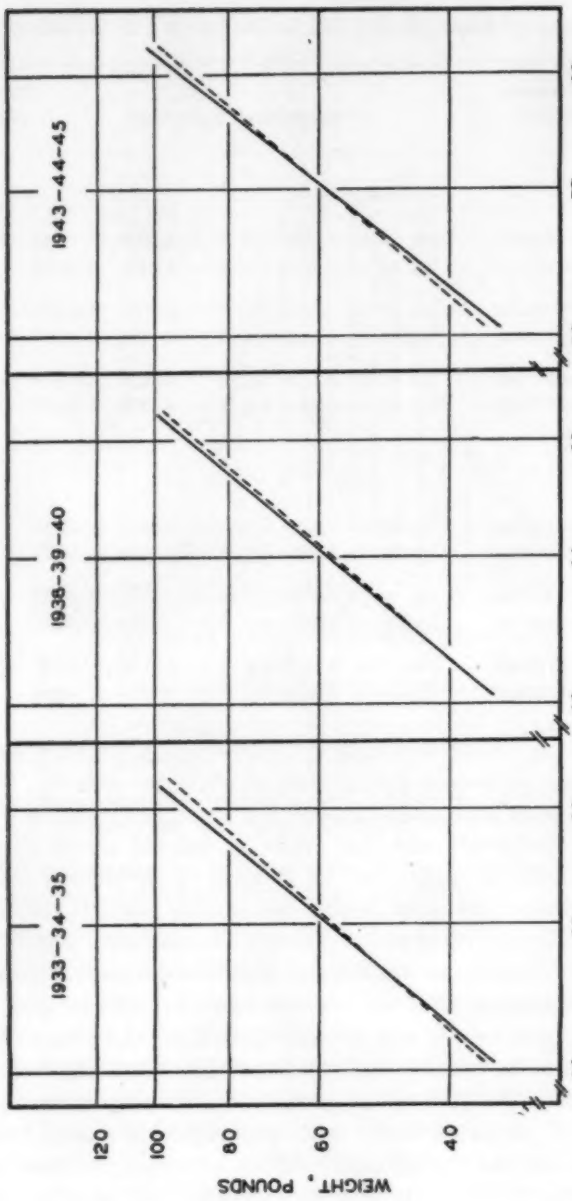

FIG. 3. AVERAGE RELATION OF HEIGHT AND WEIGHT OF BOYS FROM TWO SOCIO-ECONOMIC GROUPS IN EACH OF THREE PERIODS, LOGARITHMIC SCALE

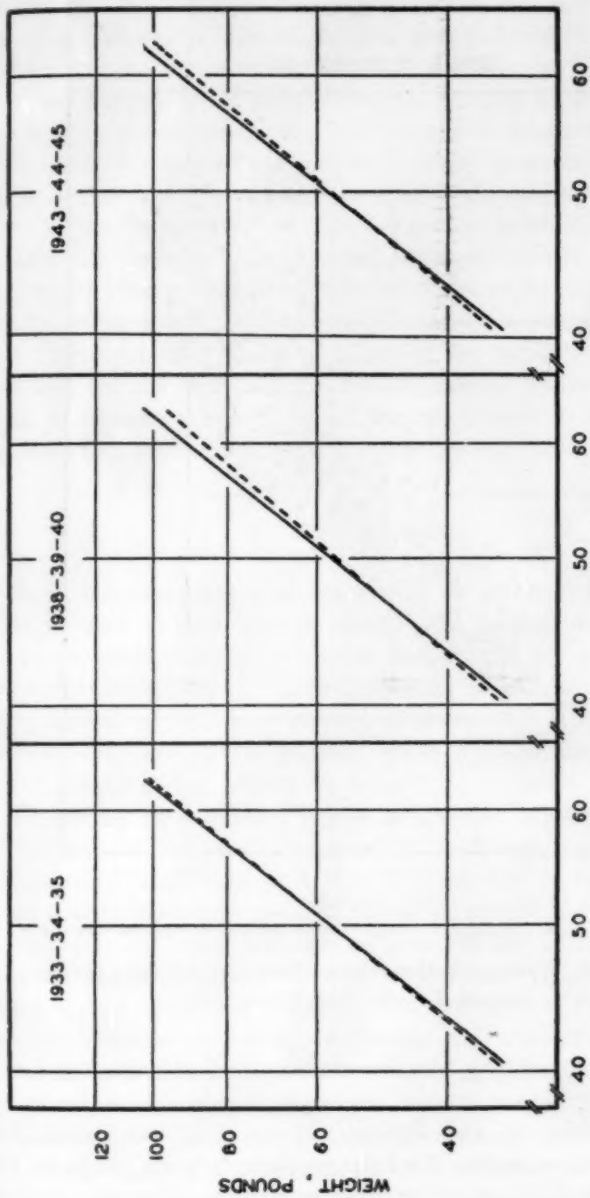

FIG. 4. AVERAGE RELATION OF HEIGHT AND WEIGHT OF GIRLS FROM TWO SOCIO-ECONOMIC GROUPS IN EACH OF THREE PERIODS, LOGARITHMIC SCALE

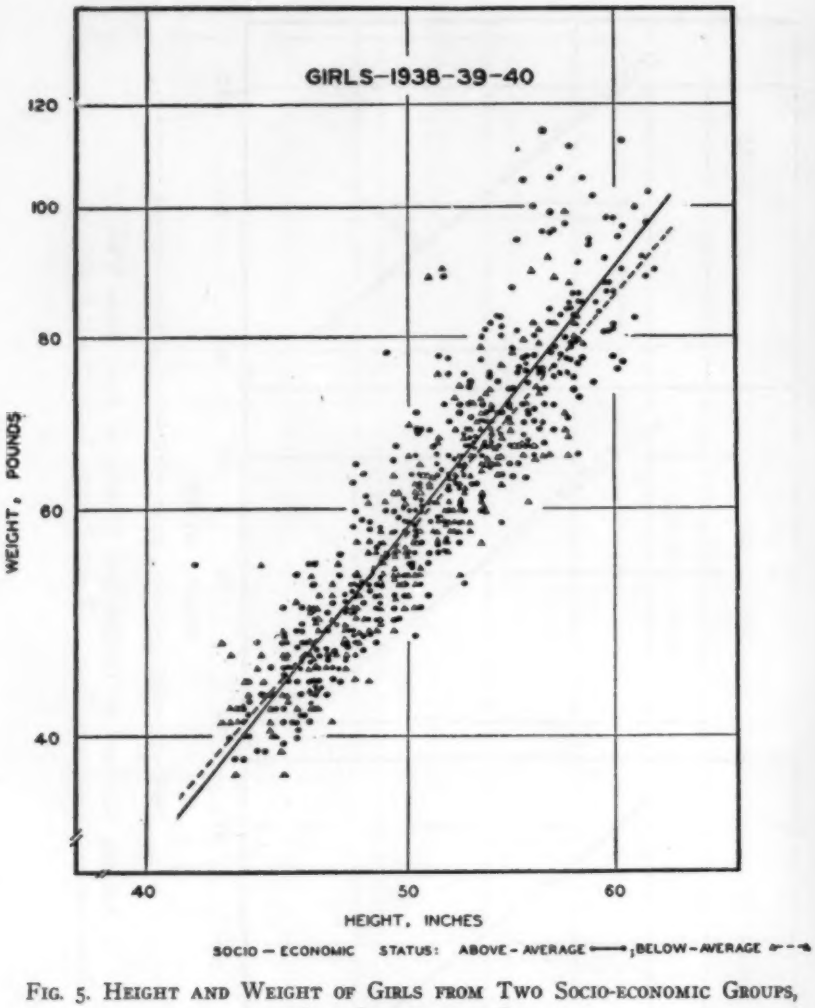

FIG. 5. HEIGHT AND WEIGHT OF GIRLS FROM TWO SOCIO-ECONOMIC GROUPS, 1938-40, LOGARITHMIC SCALE

so will be evident from Fig. 5, in which the extent of individual variation is shown.

Although the 1933-35 and 1938-40 Ottawa data were productive of some slight differences in the height-weight patterns deduced for boys and for girls, in 1943-45 the relation was the same for children of both sexes of the same economic group. Apart from this, no pro-

gressive modification over the 10-year period was noted. The coefficients of correlation of log height and weight listed in Table 6 are all of the order of 0.9, while the standard deviation of individual weights about the various trend lines averages ± 0.036 logarithmic units for boys and ± 0.042 for girls. This standard deviation, which corresponds to about 9 and 10 per cent respectively in terms of actual poundage, is an index of the variation in weight of individual children of the same height irrespective of age. Further subdivision of the data revealed that there were, as expected, some statistically detectable differences in the average weight of children of the same height but of different ages. The extent to which the dissimilarities in height-weight relations illustrated in Figs. 3 to 5 would be modified by making due allowance for the fact that the average age of children of a specified height was somewhat lower in the better-off than in the poorer group may therefore form the subject of a further communication.

CONCLUSIONS

From the foregoing analysis it may be inferred that there was a slight increase in both average stature and average weight of Ottawa elementary school children over the period 1933 to 1945, and that this was detectable earlier in better-class than in poorer children. There was, however, a persistent average difference between children of the two socio-economic strata studied, which even in 1943-45 exceeded 1 inch in height and 3 pounds in weight.

Variability in individual height and weight showed no trend over the period. It increased progressively with age, and weight was in general more variable in girls than in boys, and in the better-off than in the poorer children. Within the same period, socio-economic, and age classification, taller and shorter than average children were equally common, but individuals markedly above and slightly below average weight were respectively somewhat more numerous than those slightly above and markedly below. Although the two quantities varied to some extent independently, the coefficient of linear correlation of the logarithms of individuals' height and weight irrespective of age was of the order of 0.9. The regression differed slightly in the two socio-economic groups, so that as stature increased, the better-class children became, on the average, progressively heavier relative to the poorer children of the same height.

ACKNOWLEDGMENTS

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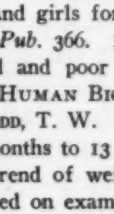

SURVIVORSHIP IN ABORIGINAL POPULATIONS

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BY definition an aboriginal population is one which exists in a more or less stabilized environment and has never been disturbed by influences emanating from one of the higher civilizations. Consequently, in theory at least, the demography of such a population could be studied only prior to any contact with the more advanced races. A strict application of this principle would entirely preclude any knowledge of vital statistics unless such data were assembled and recorded by the aborigines themselves. There are, however, two avenues of information whereby it becomes possible to derive a general idea of survivorship, although not in the statistical form familiar to students of modern populations. The first source consists of necessarily crude censuses and estimates made by the first civilized persons, such as soldiers, explorers and missionaries, entering hitherto untouched territory. They must be the first, since their own presence may alter the composition of the population. In the past some of these persons have counted the inhabitants and have attempted a crude segregation according to age. The second source includes the skeletal material unearthed by the archaeologists. When these remains are competently handled by physical anthropologists it becomes possible to determine the age at death for each skeleton. Hence we may obtain a fair idea of the age to which the population as a whole survived.

The records secured by pioneer observers among primitive peoples, particularly for Australia and North America, have been thoroughly examined by Krzywicki [1] in his volume on primitive society. Apart from purely qualitative statements he cites no instance where segregation

[1] Krzywicki, L., Primitive Society and its Vital Statistics. Macmillan, *London*, 1934.

by age has proceeded farther than a mere differentiation between children and adults. However, he concludes that primitive and aboriginal races consistently show a higher percentage of children than do the more sophisticated cultures, and therefore that fewer of the former groups survive to an advanced age than of the latter groups In support of this thesis he has compiled data including 33 cases from all over the world. The age limits of the children center around 18 years for males and 16 years for females. The mean of his values is 45.4 per cent children, with a standard deviation of ±6.93 per cent.

It is of interest to compare this figure for at least semi-aboriginal populations with some which we know to be definitely advanced beyond the aboriginal state. This comparison is shown in Table 1.

TABLE 1

Percentage of children in certain population groups

POPULATION GROUP	PERCENTAGE OF CHILDREN
Data from Krzywicki (mean)	45.4 (S.D. = ±6.93)
Indians in 2 California missions (ca. 1800)	39.3
Indians at Hupa reservation, Calif. (1887)	38.0
All Indians in California (1928)	40.0
Germany (1910, cited by Krzywicki)	39.9
Russia (1887, cited by Krzywicki)	43.8
Mexico (1930)	44.3
United States (1880)	43.1
United States (1900)	39.4
United States (1930)	34.1

Although the proportion of children in all the other populations mentioned lies below Krzywicki's mean, nevertheless they fall within the standard deviation of his individual items. Hence it is very difficult to maintain that the percentage of children is necessarily higher in a certain population merely because the latter is aboriginal. Many factors, with which all students of the problem are familiar, will operate within this age group irrespective of the cultural status. Otherwise we would be forced to the absurdity that in approximately the year 1880 the white population of the United States passed from an aboriginal or primitive state into one of maturity and enlightenment.

Derived from the second, or archaeological, source of information, eight cases are presented in tabular form in Table 2. Each one repre-

sents the result of an independent investigation wherein prehistoric human remains were excavated and the age at death determined. It is unfortunate that the number of individuals is uniformly small, and hence poorly suited to adequate statistical treatment. Such, however, is the inevitable consequence of the extreme difficulty of prosecuting this type of research. Since the data in certain instances are incomplete with respect to age segregation and since the numbers are small throughout it has appeared preferable to make the limits of the age groups rather wide. In effect the subdivision is three-fold: birth to age 20, middle age (20-50), and old age (over 50). For comparative purposes there have been added five items, all pertaining to the California and neighboring Indians, which are calculated from age distributions derived in turn from reasonably adequate censuses and which depict in broad fashion the effect of American immigration on the aboriginal population. Owing to the necessity for assuming stability in birth and death rates, and for arbitrarily assigning numerical values to the birth rates the values can be regarded only as approximations.

Between the aboriginal as well as the more recent groups there is considerable variation. This can be ascribed partially but not entirely to inadequate sampling and inaccurate determination of age at death. It is referable also to those racial or environmental differences which must inevitably be present. On the other hand there are certain consistent trends shown by the aboriginal populations as opposed to the post-contact Indians. The mean percentage of individuals dying prior to 20 years of age for the eight aboriginal aggregations is 28.8; that for the five modern Indian groups is 39.6. There appears to be a higher mortality among the latter than the former. Nevertheless the critical ratio of the means is only 1.61, a value lying at the 8 per cent level of probability. The difference can therefore not be said to possess much statistical significance. This conclusion supports the failure to find a real distinction between primitive and modern populations with respect to relative number of young people surviving, as previously pointed out. One must conclude therefore that survival up to adulthood is substantially the same in all levels of civilization.

The comparable values for deaths during middle age, from 20 to 50 years, are respectively 58.8 per cent and 23.3 per cent, and for deaths over age 50 are respectively 17.7 per cent and 36.4 per cent. The critical ratios of the means are, for the middle-aged segment, 4.65 (at the 0.3 per cent level of probability), and for the old persons, 3.50 (0.8 per

TABLE 2

Percentage distribution of deaths by broad age groups

POPULATION	AGE GROUPS							TOTAL NUMBER
	0–19	20–50	50+	0–9	10–19	20–40	40+	
I. Aboriginal populations								
West African Negroes (Todd) (1)	19.0	70.8	10.1			60.8	20.1	189
Tasmanians (Todd) (1)	37.5	46.9	16.6	3.1	34.4	40.6	21.9	32
Indians, Madisonville, Ohio (Hooton) (2)	38.8			35.1	3.7			521
Indians, Hamilton Co., Ohio (Hooton) (3)	24.7	52.1	23.3	13.7	11.0			73
Indians, California (McCown) (4)	22.6	76.2	3.2	11.4	11.2	65.9	13.4	537
Indians, Swarts ruin, New Mex. (Howells) (5)	48.6			45.7	2.9			1 009
Indians, Pecos, New Mex. (Hooton) (6)	15.0	47.5	37.5	6.1	8.9	24.2	60.8	587
Indians, Valley of Mexico (Vaillant) (7)	23.9	59.4	15.7					138
II. American Indian populations, 1800–1928								
California missions, ca. 1800 (8)	35.9	24.6	39.8	18.3	17.6	19.1	45.3	1 378
Hupa Agency, Calif., 1887 (9)	56.2	11.9	31.8	30.0	26.2	2.5	41.2	460
Mission Agency, Calif., 1902 (10)	29.0	31.5	38.1			20.0	49.6	2 487
Carson Agency, Nevada, 1902 (11)	47.6	9.3	42.2	30.4	17.2	4.4	47.1	1 080
California, 1928 (12)	29.5	39.3	29.9	19.9	9.6	29.5	39.7	22 050

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(4) These data were kindly furnished by Prof. T. D. McCown, who personally has determined the age at death of a portion of the material in the Museum of Anthropology at the University of California, Berkeley.

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(8) These are calculated values from two censuses, taken at Mission San Luis Obispo in 1794 and Mission San Francisco Solano in 1826. The censuses are printed on page 36 of "Population Trends among the California Mission Indians" by S. F. Cook, *Univ. Calif. Publ., Ibero-Americana*, no. 17, 1940.

(9) Values calculated from a census taken at the Hupa Reservation in 1887, and now in the agency files at Eureka, California.

(10) Values calculated from a census taken at the Mission Reservation in 1920 and now in the agency files at Riverside, California.

(11) Values calculated from a census taken at the former Nevada and Walker River Reservations in 1902 and now in the files of the Carson Agency, Stewart, Nevada. The population is mixed Paiute and Washo from the western edge of the Great Basin along the Nevada-California boundary.

(12) Values calculated from the 1928 census of all Indians living in California. This census was authorized by act of Congress in order to fulfill the terms of the treaty of Guadalupe Hidalgo (1848) with respect to the California natives. The complete returns are on file at the agency at Sacramento, California.

cent level). Even with the small number of cases these differences are significant.

It follows, therefore, that in so far as one may rely upon the evidence of archaeology and physical anthropology there was a definite tendency among the prehistoric aboriginal populations for the individuals to survive only into the middle period of life and to die prior to what we regard as old age. Certain further deductions are also possible. From the California situation it is apparent that survivorship, in the American red race at least, is not determined by genetic or constitutional physiological factors. The extremely short life of the aboriginal inhabitants, illustrated by the sample shown in Table 2, is a phenomenon well known to all local archaeologists. Yet even as early as the mission period in the late eighteenth century the age distribution had shifted, and among the Paiute and Washo in 1902, when there had been very little dilution of pure Indian blood, approximately two fifths of the population was surviving to an age of at least fifty.

Since we cannot invoke intrinsic determinants of survivorship among these peoples, it is necessary to conclude that the controlling forces are extrinsic or environmental. Prior to the advent of disturbing foreign human invaders, most primitive races maintain themselves without serious losses from war or disease. There are left primarily nutritional, social and economic factors. If the food supply is adequate and living conditions reasonably moderate the individual has a fair chance for survival. With respect to these elements it is illuminating to contrast the California and the Pecos groups. The former were hunter-gatherers, with few implements, no pottery, living predominantly on fish, game, acorns and roots. The latter were organized as a pueblo or town, with a highly developed material culture and supported in large part by a fairly effective agriculture. The mean length of life was probably greater by twenty years among the latter people.

But these forces—food supply, security, living conditions—and their concomitant social pressures are precisely those which affect birth rates, mortality, age distribution and survivorship in any aggregation of human beings. One is forced to the opinion, therefore, that despite apparent demographic variation, aboriginal races react to their environment in precisely the same manner as do all other animal and human populations.

ADDENDUM

When this paper was read at a joint meeting of the American Ecological Society and the Biometric Section of the American Statistical Association at Boston in December, 1946, several members of the audience commented upon the low infant mortality rate apparently shown by these figures.

For six of the aboriginal populations cited in Table 2, estimates of mortality between birth and nine years of age are available. The unweighted mean of these is 19.1 per cent. If the figures are weighted by the numbers of deaths, the mean is 27.6 per cent. If we take 20 per cent as generally representing the situation, it is safe to assume that half of these deaths occurred in infancy. (Vaillant's data for the Valley of Mexico show one tenth of the skeletons to have been infants.)

That among aboriginal or primitive populations no more than approximately ten per cent of all deaths are of infants is certainly at variance with current conceptions. It is possible that the archaeological data are at fault, either through failure of the tribesmen to bury dead infants or through negligence on the part of the excavators. Neither of these possibilities appears very likely, however, particularly in North America, where infants were generally interred carefully and where the archaeological technique has been quite adequate.

It must be remembered that modern concepts regarding this matter are derived largely from observation of (1) decadent aboriginal tribes which are heavily infected with disease and pushed beyond tolerance economically, and (2) vast and grossly overpopulated areas such as India and China where disease is rampant and where the inhabitants are living on the barest margin of subsistence. Truly aboriginal peoples were remarkably free from infections and epidemic disease (*cf.* Cook, S. F., *Hispanic American Historical Review,* 26: 320, 1946). Moreover, they were, barring invasions and cataclysms, in equilibrium with the food supply. The factors predisposing to infant mortality, therefore, exerted a relatively mild influence.